PB85-107274

Field Manual - Performance Evaluation and Troubleshooting at Metal-Finishing Wastewater Treatment Facilities

Engineering-Science, Inc., Atlanta, GA

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

Sep 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-107274

EPA-600/2-84-152
September 1984

FIELD MANUAL

PERFORMANCE EVALUATION AND TROUBLESHOOTING AT METAL-FINISHING WASTEWATER TREATMENT FACILITIES

by

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REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-84-152	2.	3. RECIPIENT'S ACCESSION NO. PB85 107274
4. TITLE AND SUBTITLE Field Manual-Performance Evaluation and Troubleshooting at Metal Finishing Wastewater Treatment Facilities		5. REPORT DATE September 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) T. N. Sargent, G. C. Patrick and E. H. Snider		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Engineering-Science, Inc. Atlanta, GA 30329		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-03-3040 (SBE02)
12. SPONSORING AGENCY NAME AND ADDRESS U. S. Environmental Protection Agency Industrial Environmental Research Laboratory Industrial Pollution Control Division Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 1983
		14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This manual provides a technical field guide or reference document for use in improving the performance of facilities for the treatment of metal finishing wastes. The main purpose of the manual is to provide a troubleshooting guide for identifying problems, analyzing problems, and solving problems. The manual describes general procedures for evaluating the performance of treatment processes and equipment commonly used in metal finishing waste treatment. The procedures also cover other items related to the effective operation of treatment facilities. The methodology used to evaluate compliance problems and develop Operation and Maintenance (O&M) specifics are described in a review of the literature, followed by an assessment of the causes of permit violations and the recommended measures for improving compliance. The unit processes described in this manual are those commonly used in the treatment of metal finishing wastes. They are the following: equalization, oil removal, cyanide oxidation, chromium reduction, pH control, metal precipitation, flocculation, sedimentation, filtration, gravity thickening, belt filter presses, vacuum filtration, pressure filtration for dewatering, and centrifugation. For each of these unit processes, the manual contains information on theory of operation, description of equipment, operational procedures, typical performance values, and a troubleshooting guide.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Metal Finishing Electroplatinng Wastewatter Treatment		

18. DISTRIBUTION STATEMENT RELEASE UNLIMITED	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 282
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

For the first time, an operating and troubleshooting manual has been put together to assist plant operators and managers of wastewater treatment plants for the metal finishing industry. This performance evaluation and troubleshooting guide has been reviewed by true experts of plating wastewater treatment - the plant operators. Without their day to day insight into operational and maintenance problems, the initial field manual effort would not have been possible.

A more detailed development of this guide is destined for the future. Only by widespread use and evaluation can this manual be revised and upgraded to reflect the current and future trends of complex treatment and control technology systems required for the metal finishing industry. It is hoped that this field manual will guide plant operators in achieving consistently higher performance levels.

Requests for further information regarding this field manual on performance and troubleshooting at metal finishing wastewater treatment facilities should be directed to the Industrial Pollution Control Division, IERL, Cincinnati.

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ABSTRACT

This manual provides a technical field guide or reference document for use in improving the performance of facilities for the treatment of metal-finishing wastes. The main purpose of the manual is to provide a troubleshooting guide for identifying, analyzing, and solving problems.

The manual describes general procedures for evaluating the performance of treatment processes and equipment commonly used in metal finishing waste treatment. The procedures also cover other items related to the effective operation of treatment facilities.

The methodology used to evaluate compliance problems and develop Operation and Maintanence (O&M) specifics are described in a review of the literature, followed by an assesment of the causes of permit violations and the recommended measures for improving compliance.

The unit processes described in this manual are those commonly used in the treatment of metal finishing wastes. They are the following: equalization, oil removal, cyanide oxidation; chromium reduction, pH control, metal precipitation; flocculation, sedimentation, filtration; gravity thickning, belt filter presses, vaccum filtration; belt filtration for dewatering, and centrifugation. For each of these unit processes, the manual contains information on theory of operation, description of equipment, operational procedures, typical performance values, and troubleshooting guide.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

A:S - Air to Solids Ratio
API - American Petroleum Institute
DAF - Dissolved Air Flotation
HRT - Hydraulic Retention Time
IAF - Induced Air Flotation
ORP - Oxidation-Reduction Potential
PI - Proportional Plus Integral
PID - Proportional-Integral-Derivative
SOR - Surface Overflow Rate
SS - Suspended Solids Concentration
SVR - Sludge Volume Ratio
TSS - Total Suspended Solids Concentration

Symbols

C - Concentration
C_e - Effluent TSS Concentration
C - Influent TSS Concentration
C_i - Influent TSS Concentration to Clarifier
C_R - Sludge TSS Concentration
MVG - Mean Velocity Gradient for Flocculation
M - Dynamic Viscosity
P - Power Input for Flocculation
PD - Polymer Dosage
q - Polymer Flowrate
Q_w - Flowrate of Wastewater
Q_e - Effluent Flowrate
Q - Influent Flowrate
Q_i - Influent Flowrate to Clarifier
Q_R - Sludge Removal Flowrate
SL - Solids Loading
V - Volume

SECTION 1

INTRODUCTION

PURPOSE AND SCOPE OF MANUAL

The purpose of this manual is to provide a technical field guide or reference document for use in improving the performance of facilities for the treatment of metal finishing wastes. The main purpose of the manual is to provide a troubleshooting guide for the following: 1) identifying problems, 2) analyzing problems, and 3) solving problems.

Plant personnel responsible for waste treatment processes and achieving permit compliance must be knowledgeable about not only the problem areas, but also with electroplating and related metal finishing concepts and in-plant process modifications and changes as they relate to the waste treatment processes. This manual describes general procedures for evaluating the performance of treatment processes and equipment commonly used in metal finishing waste treatment. The procedures also cover other items related to the effective operation of treatment facilities. Troubleshooting guides, operating strategies, and process monitoring material are discussed in detail for each unit process commonly used in metal finishing waste treatment.

MANUAL FORMAT

It is assumed that the manual user has a general understanding of treatment facilities and their operation. The style, language, and format of the manual are directed to the level and technical knowledge of a technician with some experience with in-plant operation, design, inspection, or performance evaluation.

The manual is organized into the following major sections:

Section 1 INTRODUCTION. The purpose, scope, and format of the manual are described in this section.

Section 2 CONCLUSIONS AND RECOMMENDATIONS. The major conclusions and recommendations regarding compliance problems and development of O&M specifics are described in this section.

Section 3 PROBLEM ASSESSMENT AND RECOMMENDATIONS FOR IMPROVING PERMIT COMPLIANCE. The causes of permit violations and the recommended measures for improving compliance are described in this section.

Sections 4 through 17. UNIT PROCESS EVALUATION AND TROUBLESHOOTING INFORMATION. For each unit process commonly used in the treatment of metal finishing wastes, this section contains the following information:

- Introduction
- Theory of Operation
- Description of Equipment
- Operational Procedures
- Typical Performance Values
- Troubleshooting Guide

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This manual details performance evaluation of wastewater treatment facilities for metal-finishing wastes. Troubleshooting guides on unit process operations are included to help pinpoint causes of treatment malfunctions.

It is concluded that operators and owners of metal-finishing plants can utilize this manual to help bring their wastewater treatment facilities into compliance. This can be accomplished best by a joint effort on the part of management and the operators.

Monitoring of treatment parameters is the key factor in determining performance of facilities and an early warning for non-compliance trends.

The purpose of this manual is to provide a technical field guide or reference document for use in improving the performance of facilities for the treatment of metal finishing wastes. The main purpose of the manual is to provide a troubleshooting guide for the following: 1) identifying problems, 2) analyzing problems, and 3) solving problems.

Plant personnel responsible for waste treatment processes and achieving permit compliance must be knowledgeable about not only the problem areas, but also with electroplating and related metal finishing concepts and in-plant process modifications and changes as they relate to the waste treatment processes. This manual describes general procedures for evaluating the performance of treatment processes and equipment commonly used in metal finishing waste treatment.

The literature search also included equipment manufacturers' information, data provided by professional organizations, and communications with personnel who were familiar with the treatment and disposal of metal finishing wastes.

The objectives of the literature review were to collect data which would aid in identifying the major causes of permit violations, and to collect information which could be used to develop operation and maintenance (O&M) specifics qualifying this data and information, methods and techniques for improving compliance of facilities could be developed.

An analysis of permit violations was conducted to understand the problems associated with treatment of metal finishing wastes. The troubleshooting manual was then prepared to address the problems. An analysis of permit violations was performed utilizing the Quarterly Noncompliance Report published by the Office of Water of the United States Environmental Protection Agency. The report listed the major industries that were out of compliance and the parameters that were out of compliance. The violations in the Noncompliance Report were listed by SIC code. The SIC numbers used for identifying industries with metal wastes were 3471 (electroplating), 3631, 3632, 3633, 3639, 3714, 3721, and 3731.

Operation and Maintenance (O&M) specifics for the treatment of metal finishing wastes were obtained from a search of technical publications, a computerized literature search, and contacts with equipment manufacturers and operators. The information collected from these sources was then interpreted and compiled. This field manual was developed from information obtained from these sources.

It is assumed that the manual user has a general understanding of treatment facilities and their operation. The style, language, and format of the manual are directed to the level and technical knowledge of a technician with some experience with in-plant operation, design, inspection, or performance evaluation.

Recommendations

The level of pollutants discharged to publicly owned treatment works by plants following pretreatment must meet new regulations. The electroplating and metal-finishing point source categories is regulated by the USEPA (Federal Register, 48(137), 32462-32488J July 15, 1983).

Improving the level of permit compliance for treatment of metal-finishing wastes is a two-step process. The first step is to identify the problem and the second step is to take the necessary corrective actions. Permit compliance problems are generally in the following four categories: 1) design, 2) operation, 3) administration, and 4) maintenance.

The importance of proper design cannot be overstated. Each unit process, along with the integrated waste treatment system, must be designed with numerous factors accounted for. An improperly designed system seldom operates well. Design improvements to enhance permit compliance is a long-term process; near-term improvements are seldom attainable through design changes.

Performance of a well-designed system may be affected by improper operating procedures. Thus, an operator's familiarity with correct O&M procedure can directly improve operation of a system. It is the goal of this publication to provide adequate O&M procedures and troubleshooting guides to produce improved levels of permit compliance in metal-finishing waste treatment plants.

Administration affects permit compliance, although often in an indirect manner. Such items as staff supervision, motivation, funding, and planning affect the operation of a facility, which, in turn, affects all aspects of the treatment plant.

Finally, maintenance affects permit compliance directly. In numerous instances throughout the descriptions that follow, routine inspection and maintenance are cited as the chief deterrents to operating problems, and hence to permit violations. A competent, well-trained maintenance group is indispensable in the smooth and successful operation of a treatment plant.

Although the tendency is to categorize permit compliance problems as belonging strictly to one of the four areas discussed above, the fact is that most problems have aspects of two or more areas. Plants owners and operators that hope to improve permit compliance must strive to achieve improvement in all four categories.

RESOURCE RECOVERY RECOMMENDATIONS

Pollution control legislation has affected industry by increasing the economic penalty associated with inefficient use of resources. In the plating industry, for example, loss of a raw material in the wastewater can result in three distinct cost items: replacement of the material, removal of the material from the wastewater before discharge, and disposal of the residue. Similar cost items exist for process water: replacement of water (no longer inexpensive to purchase) used in processing, processing the water in the wastewater treatment system, and processing in the water by the treatment plant after discharge into a public sewer system.

In response to the increased cost of raw material losses, plating shop processes are being modified to reduce these losses as well as water consumption. Recent years also have seen the cost-effective application of various separation processes that reclaim plating chemicals from rinse waters, enabling both the raw material and the water to be reused.

The impact of resource recovery and pollutant load reduction modifications on waste treatment and solid waste disposal costs must be measured, if these modifications are to be evaluated. Cost of sophisticated treatment necessary for electroplating wastewater and of residue disposal often provides a significant economic incentive for resource recovery.

REDUCED LOADING RECOMMENDATIONS

Modifications that will reduce the pollutants or wastewater loadings on a treatment facility range from using flow restrictors to eliminate excess dilution in rinse tanks to installing recovery units, such as reverse osmosis and evaporation, to separating plating chemicals from rinse water for recycle to the plating bath. Actions that can minimize wastewater volume include the following:

1) Implementing rigorous housekeeping practices to locate and repair water leaks quickly,
2) Employing multiple counterflow rinse tanks to reduce rinse water use substantially,

3) Employing spray rinses to minimize rinse water use,
4) Using conductivity cells to avoid excess dilution in the rinse tanks,
5) Installing flow regulators to minimize water use, and
6) Reusing contaminated rinse water and treated wastewater where feasible.

Steps to minimize pollutant loadings include:

- Implementing a rigorous housekeeping program to locate and repair leaks around process baths,
- Replacing faulty insulation or plating racks to prevent excessive solution drag-out,
- Installing drip trays where needed,
- Using spray rinses or air knives to minimize solution drag-out from plating baths,
- Recycling rinse waters to plating bath to compensate for surface evaporation losses,
- Using spent process solutions as wastewater treatment reagents (acid and alkaline cleaning baths are obvious examples),
- Using minimum process bath chemical concentrations,
- Installing recovery processes to reclaim plating chemicals from rinse waters for recycle to the plating bath, and
- Using process bath purification to control the level of impurities and prolong the bath's service life.

Closed-loop chemical recovery from a rinse stream can often provide the solution to treat. Applying a closed-loop recovery system to a plating operation eliminates the need to treat the rinse water normally associated with that step.

In the case of rinse streams requiring pretreatment (for examples, cyanide or chromium) or rinses containing pollutants not effectively removed by conventional end-of-pipe technology (for example, some types of complexed metals), installing a closed-loop system to recycle the rinse may reduce the investment needed to comply with the effluent quality limitations.

SECTION 3

PROBLEM ASSESSMENT AND RECOMMENDATIONS FOR IMPROVING PERMIT COMPLIANCE

CONVENTIONAL WASTEWATER TREATMENT

Conventional wastewater treatment in the electroplating industry consists of the following unit processes (see Figure 1):

- Chromium reduction (if needed) of segregated chromium waste streams to reduce the chromium from its hexavalent form to the trivalent state, which then can be precipitated as chromium hydroxide by alkali neutralization,
- Cyanide oxidation (if needed) of segregated cyanide-bearing waste streams to oxidize the toxic cyanides to harmless carbon and nitrogen compounds,
- Neutralization of the combined metal-bearing wastewaters, acid/alkali wastewaters, strong chemical dumps, and the effluent from the cyanide and chromium treatment systems to adjust the pH within acceptable discharge limits and to precipitate the dissolved heavy metals as metal hydroxides,
- Clarification, in which flocculating/coagulating chemicals are added to promote the initial settling of the precipitated metal hydroxides,
- Gravity thickening over extended time to increase solids content of sludge before disposal.

These unit processes provide effective, reliable treatment for many electroplating waste streams. That is not to say, however, that such treatment is suitable for all applications or that the "normal" design

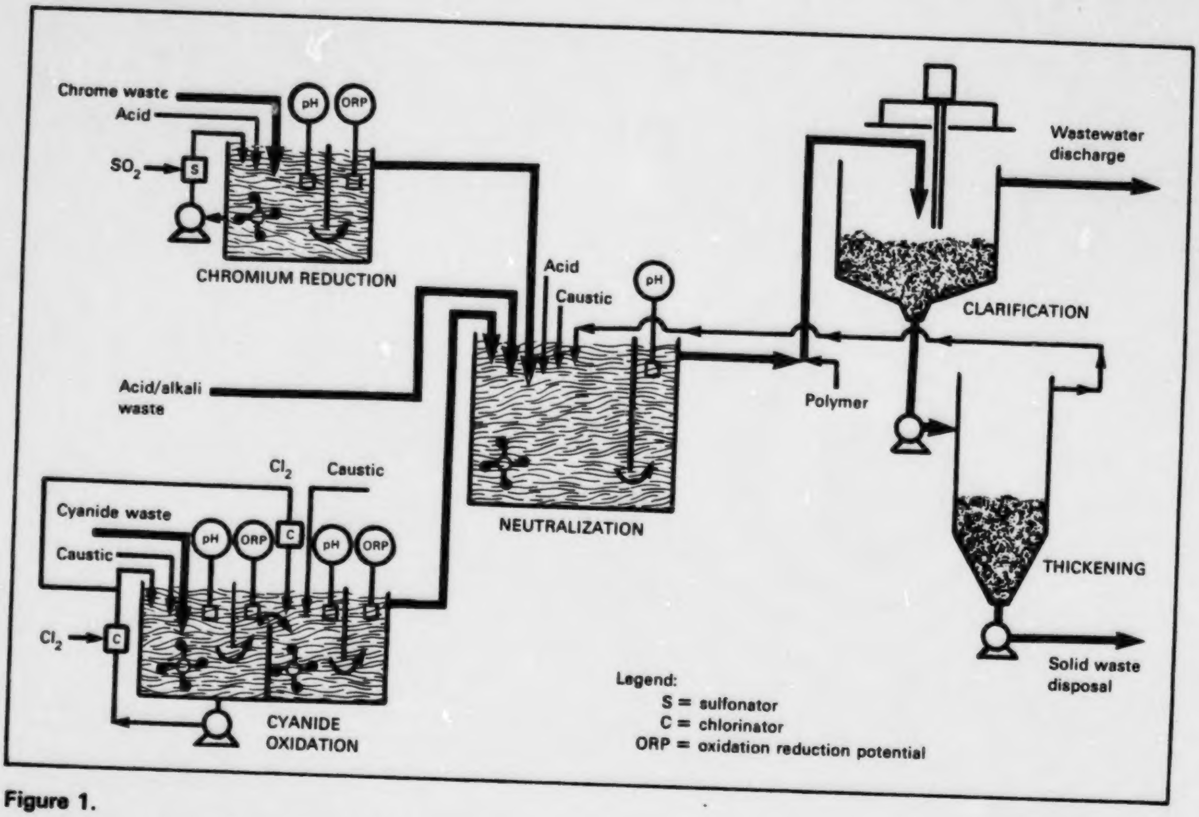
Chrome waste
Acid
SO_2
S
pH
ORP
CHROMIUM REDUCTION
Acid
Caustic
pH
Acid/alkali waste
NEUTRALIZATION
Polymer
Wastewater discharge
CLARIFICATION
THICKENING
Solid waste disposal
Cl_2
Caustic
Cyanide waste
Caustic
pH
ORP
C
pH
ORP
Cl_2
C
CYANIDE OXIDATION
Legend:
S = sulfonator
C = chlorinator
ORP = oxidation reduction potential

Figure 1.

Electroplating Industry Conventional Wastewater Treatment

SOURCE: USEPA ENVIRONMENTAL REGULATIONS AND TECHNOLOGY; THE ELECTROPLATING INDUSTRY, EPA 625/10-80-001, AUGUST 1980, P. 13.

parameters (retention time, reagent dosage, and so forth) will provide effective pollutant removal from every individual plater's wastewater discharge.

Many of the items covered in this manual have their basis in a conventional wastewater treatment system such as the one described in the preceding.

PROBLEM ASSESSMENT

A plant assessment is the initial step in a pollution control program. A plant assessment involves a thorough analysis of the operations of a metal finishing plant that relate to pollutant sources and water use. The information generated during a plant assessment is used in evaluating the application of in-plant changes for reducing chemical loss and water use.

A plant assessment includes the following steps: 1) inspection of the plating room layout, 2) review of plant operating practices, 3) examination of process water use, 4) performance of sampling and laboratory analysis to characterize waste streams and to determine dragout rates, and 5) identification of the frequency, volume, and characteristics of batch dumps.

Laboratory analyses of wastewater samples are performed using standard EPA-approved techniques. Throughout this manual, various analytical parameters and their concentrations are discussed. For all tests the analytical methodology presented in the EPA document "Methods for Chemical Analysis of Water and Wastes"(8) or "Standard Methods for the Examination of Water and Wastewater"(9) should be followed.

The successful operation and maintenance (O&M) of a waste treatment plant requires consistent performance that exceeds regulatory compliance levels. Failure to meet these compliance levels can result in costly disposal alternatives, fines, damage to the environment, and adverse public reaction. If a treatment facility fails to meet compliance standards, the problem usually falls under one of the following causes:

1) Shock loadings (hydraulic or contaminants) to the waste treatment plant,
2) Poor understanding of O&M procedures,
3) Poor process control,
4) Equipment failure, and
5) Treatment plant design inadequacies.

The potential effect of good O&M on each of the five categories of non-compliance reasons is discussed below. If a plant finds itself in non-compliance it should determine which categories of causes are applicable and take appropriate action to see if improved O&M could be effective in improving its performance.

Shock Loadings

Shock loadings of flow or contaminants frequently cause treatment process upsets which can result in non-compliance. Sources of these shock loadings can be either spills or releases from production batch operations or cleaning operations. Their impact on the treatment process can be mitigated by installing sufficient equalization. Their impact can also often be controlled by changes in operating procedures in the production facility or in the treatment plant. Of foremost importance is communication between production and waste-treatment personnel. If waste-treatment personnel are notified of potential shock loads in sufficient time, mitigating action often can be taken, such as diverting the shock load to sidestream equalization to temporarily bypass sensitive processes, or manually modifying process operating parameters to adjust for the shock loading.

Modification of production procedures with respect to spill control and operating procedures for batch processes and cleaning operations can reduce the magnitude of shock loadings in several ways. Wastes from batch or cleaning operations can be released slowly or during times of low flow. Spills can be cleaned up using dry chemicals and not be hosed down the drain. Chemical handling procedures can be modified to reduce the likelihood of spills and chemicals can be stored in diked areas to contain spills that do occur.

In all cases implementation of the above procedures requires good training of all personnel in proper operating procedures to control shock loading. Part of this training must include making production personnel aware that their procedures impact waste treatment. This factor is becoming increasingly important as some facilities have had to curtail production in order to achieve discharge compliance levels. Treatment plant personnel also must be trained in the proper operating procedures to mitigate the impact of a shock load. This action may be diverting flow to sidestream equalization, bypassing an oil water separator while a non-oily hydraulic shock load is occurring, notifying production to stop or slow an excessive discharge, or other appropriate procedures.

Poor Understanding of O&M Procedures

A good understanding of O&M procedures is essential to successfully operate a facility for the treatment of metal finishing wastes. An operator who is well versed in the proper O&M procedures can usually operate the treatment facility to meet permit compliance even though one or more of the above causes of permit violation exists at the treatment facility. This manual was developed to assist operators in implementing the proper O&M procedures at the treatment facility. While no manual can be general enough for all plants and yet specific enough for one plant, the intention of this manual is to aid in the understanding of the cause/effect relationship for several treatment processes. Once an operator has developed a cause/effect relationship for the control variables at the treatment facility, then specific adjustments and/or setpoints can be established. A successful O&M program will be attained when the operator can identify a potential problem, understand the cause of the problem and what effect it will have on compliance, and then adjust the control variables so as to mitigate the problem.

Poor Process Control

One of the most common causes of continuous poor performance and frequent non-compliance is poor process control. Poor process control results in the treatment plant not achieving its full capacity and efficiency. When the full or design efficiency is not achieved, the blame is put frequently on poor design, but it must be remembered that the design is based upon the assumption of good process control which may or may not be occurring. Good process control can only be achieved by well trained operators who know and understand their equipment and the impact of all operating variables under their control. This includes understanding the interaction between operating variables and the trade-offs often involved. As an example, increasing the belt tension in a belt filter press can result in a drier cake but will also result in more solids in the filtrate and a shorter belt life. However, the solids in the filtrate might adversely affect the performance of other treatment processes such as an oil coalescer.

Process control through good operations is particularly important in the metal finishing industry where several waste treatment processes require critical control of operating variables to achieve good treatment performance. Examples include pH control for metal precipitation, and pH and oxidation-reduction potential (ORP) control for chromium reduction and cyanide oxidation. A relatively slight change in these operating variables can result in significant degradation in performance, non-compliance, and in the case of cyanide reduction, the potential for release of toxic gases.

Equipment Failure

Equipment failure can readily cause a treatment plant to fail to meet regulatory compliance levels. The impact of the equipment failure can be minimal when repairs are implemented quickly or the impact may be major with parts and repairs taking days to obtain and install. It is therefore essential to minimize equipment failure and downtime. This minimization of downtime can be achieved partially by a sufficient parts inventory and overdesign; it also requires good operation and maintenance of existing treatment plant equipment. Mechanical equipment has a set of design operating conditions and any time these conditions are exceeded, premature equipment failure can occur. Treatment plant personnel should be aware of these design conditions and integrate them with plant operating procedures to insure that mechanical equipment is not unduly stressed. It should be noted that this stress does not always come from mechanical forces. Improper pH levels can corrode equipment and excessively high temperatures can cause materials of construction to fail. Once equipment failure has occurred, prompt repair of equipment by well trained maintenance personnel is essential to minimize the impact and prevent recurrence.

Good operations and maintenance can also prevent equipment failure by a regular and orderly inspection of equipment for wear or other early signs of equipment failure such as vibration. A good preventive maintenance program is another essential facet of preventing premature equipment failure.

Treatment Plant Design Inadequacies

No amount of good operations and maintenance can make a poorly or improperly designed treatment plant achieve consistent compliance with regulatory standards; conversely, poor operations and maintenance can make even the best designed treatment plant fall into noncompliance. Before any major design modifications are implemented, the potential for treatment plant performance improvement through improved O&M should be investigated thoroughly.

RECOMMENDATIONS FOR IMPROVING PERMIT COMPLIANCE

The level of pollutants that may be discharged to publicly owned treatment works (POTW) is regulated by the USEPA. Specifically, the level of pollutants dischargable by a plant falling within the electroplating and metal finishing point source categories is limited by regulations issued in the Federal Register on July 15, 1983.(10) A copy of these regulations is included as Appendix B of this manual.

Improving the level of permit compliance for treatment of metal finishing wastes is a two-step process. The first step is to identify the problem and the second step is to take the necessary corrective actions. Permit compliance problems generally will fall into the following four categories: 1) design, 2) operation, 3) administration, and 4) maintenance.

As mentioned elsewhere in this report, the importance of proper design cannot be overstated. Each unit process along with the integrated waste treatment system must be designed with numerous factors accounted for. A system which is improperly designed will seldom be a system which can be operated well. Improvement of permit compliance by improving design is a long-term process; near-term improvements are seldom attainable through design changes.

A well-designed system may not perform as expected because of improper operating procedures. A number of instances of improper operation have existed; improvement of operation is a direct function of the operators' familiarity with correct O&M procedures. It is the goal of this publication to provide adequate O&M procedures and troubleshooting guides to produce improved levels of permit compliance in metal finishing waste treatment plants.

Administration also affects permit compliance, although often in an indirect manner. Such items as staff supervision, motivation, funding, and planning affect the operation of a facility, which in turn affects all aspects of the treatment plant.

Finally, maintenance affects permit compliance directly. In numerous instances throughout the descriptions which follow, routine inspection and maintenance are cited as the chief deterrents to operating problems, and hence to permit violations. A competent, well-trained maintenance group is indispensable in the smooth and successful operation of a treatment plant.

Although the tendency is to categorize permit compliance problems as belonging strictly to one of the four areas discussed above, in fact most problems have aspects of two or more areas. A plant which hopes to improve its permit compliance must strive to achieve improvement in all four areas.

RESOURCE RECOVERY(1)

Pollution control legislation has affected industry by increasing the economic penalty associated with inefficient use of raw materials. In the plating industry, for example, loss of a raw material in the wastewater can result in three distinct cost items: replacement of the material, removal of the material from the wastewater before discharge, and disposal of the residue. Similar cost items exist for process water: replacement of water (no longer inexpensive to purchase) used in processing, preparation of the water in a treatment system, and processing of the water by the waste treatment plant after discharge into a sewer system.

In response to the increased cost of raw material losses, plating shops are modifying their processes to reduce these losses as well as water consumption. Recent years also have seen the cost-effective application of various separation processes that reclaim plating chemicals from rinse waters, enabling both the raw material and the water to be reused.

The impact of resource recovery and pollutant load reduction modifications on waste treatment and solid waste disposal costs must be measured if these modifications are to be evaluated. Cost of sophisticated treatment necessary for electroplating wastewater and of residue disposal often provides a significant economic incentive for resource recovery.

Modifications for reducing the pollutant or wastewater loading on a treatment facility range from using flow restrictors to eliminate excess dilution in rinse tanks to installing recovery units, such as reverse osmosis and evaporation, to separating plating chemicals from rinse water for recycle to the plating bath. Actions that can minimize wastewater volume include the following:

- Implementing rigorous housekeeping practices to locate and repair water leaks quickly,
- Employing multiple counterflow rinse tanks to reduce rinse water use substantially,
- Employing spray rinses to minimize rinse water use,
- Using conductivity cells to avoid excess dilution in the rinse tanks,
- Installing flow regulators to minimize water use,
- Reusing contaminated rinse water and treated wastewater where feasible.

Steps to minimize pollutant loading include:

- Implementing a rigorous housekeeping program to locate and repair leaks around process baths, replacing faulty equipment on plating racks to prevent excessive solution drag-out, installing drip trays where needed, and so forth,
- Using spray rinses or air knives to minimize solution drag-out from plating baths,
- Recycling rinse water to plating bath to compensate for surface evaporation losses,
- Using spent process solutions as wastewater treatment reagents (acid and alkaline cleaning baths are obvious examples),
- Using minimum process bath chemical concentrations,
- Installing recovery processes to reclaim plating chemicals from rinse waters for recycle to the plating bath,
- Using process bath purification to control the level of impurities and prolong the bath's service life.

Closed-loop chemical recovery from a rinse stream can often provide the solution to handling wastes that are difficult or expensive to treat. Applying a closed-loop recovery system to a plating operation eliminates the need to treat the rinse water normally associated with that step.

In the case of rinse streams requiring pretreatment (for example, cyanide or chromium) or rinses containing pollutants not effectively removed by conventional end-of-pipe technology (for example, some types of complexed metals), installing a closed-loop system to recycle the rinse may reduce the investment needed to comply with the effluent quality limitations.

SECTION 4

EQUALIZATION

INTRODUCTION

One of the most frequently encountered problems in metal finishing wastewater treatment is process upsets related to intermittent high flowrates and highly variable contaminant levels. Batch discharge of high strength plating solutions and plating wastes often can cause large fluctuations in flowrates, pH, metals concentrations, cyanide concentration, and other critical contaminant levels. These fluctuations are often so severe that process upset and subsequent permit violations can occur before the system is able to compensate. For this reason, wastewater equalization often is implemented to control the extreme fluctuations in flow and contaminant concentrations. Likewise, whenever treatment process upsets occur, especially on a periodic basis, proper equalization should be one of the first operating conditions to be checked.

THEORY OF OPERATION

Wastewater equalization can accomplish three basic tasks. The first is hydraulic or flow equalization which dampens hydraulic surges to downstream treatment processes. Flow equalization can only be accomplished by placing some type of variable liquid volume storage tank in the wastewater flow path upstream of sensitive process equipment. The liquid is stored in the variable volume tank during high flow periods and then is released during low flow periods. Therefore, the hydraulic equalization capability is directly related to the utilized variable volume of the tank.

The second equalization task is contaminant or concentration equalization. Contaminant equalization is accomplished by mixing low and high contaminant concentration wastewater, which results in an average concentration with dampened fluctuation. As with flow equalization, some type of storage must be provided which stores highly (or slightly) contaminated flow until such time as the contaminant concentration cycles to the other extreme. Contaminant equalization can be accomplished by placing in the flow path a storage tank and mixer with sufficient volume to mix the low and high concentration wastes or by collecting only the high concentration wastes in a storage tank and bleeding them back during periods of low contaminant concentration. The latter system has the disadvantage that the contaminant concentration must be monitored continuously and rapid action taken based on instantaneous contaminant concentration.

The third equalization task, an offshoot of the earlier discussed two, is to allow means to control the load that reaches the process within limits set by the operator. This is accomplished by positioning the outlet line near the bottom of the equalization basin and providing valving that allows the operator the option of increasing or decreasing flows to his process from the equalization basin. The operator would have the option of lowering flow during period of high concentrations and raising flows during periods of low concentrations and could control the load to the process to desired levels. This system has the disadvantage that it requires more analytical work than the other two systems and requires a larger equalization tank that will allow the operator to vary the tank level and has the advantage that it will reduce the possibility of organic shock and allows much finer control of the process.

Mixing is an integral part of all equalization techniques. Flow equalization requires mixing to keep suspended material in suspension. Without it, solids will accumulate in the storage tank thereby reducing the effective volume of the tank. Contaminant equalization requires mixing to blend the low and high strength wastes together. Typically, the mixers are vertical shafts with turbines or marine propellers. If tanks are deep, draft tubes are installed or multiple impellers are placed on elongated shafts. Horsepower requirements for equalization mixing typically run between 0.02 and 0.04 horsepower/1000 gallons if gritty material is not present in the waste.* If, however, gritty material is present, horsepower requirements for mixing can exceed 2.5 horsepower/1000 gallons. In all cases, if mixing is occurring in circular tanks, then baffles must be installed on the sidewalls.

DESCRIPTION OF EQUIPMENT

Wastewater equalization can be accomplished by a number of different methods. Some equalization occurs in sewer lines. Pollution control equipment also has some surge capacity available to dampen out fluctuations. However, due to the nature of the variations in the metal finishing industries, these methods provide little if any effective equalization. Several typical equalization methods other than inherent system equalization are described below.

Batch Processing

Equalization by batch processing involves storage and batch processing of the wastewater in the same tank. To accommodate continuous systems, multiple reactors are operated in parallel. When one reactor is full, the flow is switched to another reactor while the wastewater in the first reactor is being treated. Reactor storage capacity must be sufficient to handle the maximum volume of wastewater that could be generated during the time it takes to treat the wastewater and empty wastewater from the other reactor (see Figure 2(a)). Alternatively, the system can be operated in batch mode with one tank when the system is used to treat wastewater flows from batch type plating operations. This technique is employed often when specialized treatment is required for intermittent waste flow.

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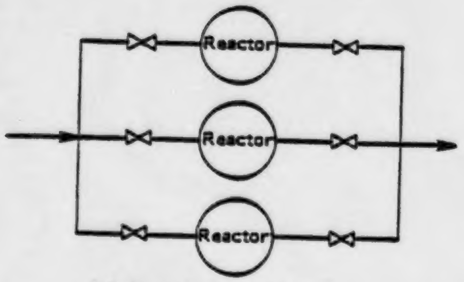
*This and the following sections present information in a mix of English Engineering and metric units. This mix of units occurs because, although metric units are now preferred for data reporting, many of the quantities are reported still almost exclusively in English units, and "rules of thumb" have been cast in these units. A table of metric-English conversions is provided with this report as Appendix C.

The batch processing procedure is a very effective equalization technique since wastewater in the treatment reactor is consistent for each treatment cycle. The system, however, requires that either the flow must be intermittent with sufficient time for wastewater treatment to occur between flows, or multiple reactors must be provided. The latter is usually prohibitively expensive. Therefore, this process is found primarily on small intermittent flows from batch metal finishing operations whose wastewater requires specialized treatment, such as plating solutions which contain high concentrations of cyanide or chromium.

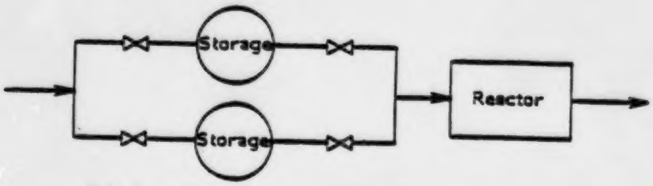
Continuous Processing from Batch Storage

Continuous processing from batch storage usually involves two storage tanks operating on a fill-and-draw cycle. While one tank is being filled, the other tank is being discharged to a waste treatment facility (see Figure 2(b)). This procedure is unlike batch processing, in which the equalization and waste treatment steps occur in the same vessel. Using this technique the waste treatment facility receives a waste stream with uniform characteristics while processing the contents of an individual tank. The stream characteristics, however, often vary significantly from tank to tank.

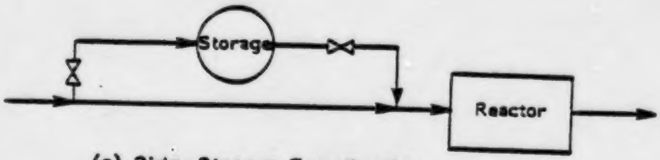
This equalization technique requires either automated influent and effluent valves controlled by level indicators in the batch equalization tanks, or intensive operator supervision. The equalization tanks must be sized such that the volume from at least one flow cycle or contaminant concentration cycle can be collected in one tank. If contaminant equalization is desired, the tanks must also be mixed. This system is best suited for relatively small flows and/or rapidly varying (cycling) flows that will permit reasonably sized tanks. Its primary deficiency


Reactor
Reactor
Reactor

(a) Batch Processing


Storage
Storage
Reactor

(b) Continuous Processing from Batch Storage


Storage
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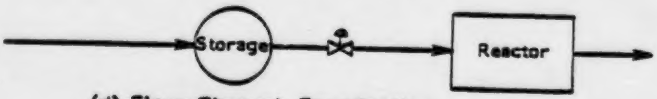
(c) Side-Stream Equalization


Storage
Reactor

(d) Flow-Through Equalization

Figure 2. **Methods of equalization.**

SOURCE: EPA REPORT NUMBER 600/2-81-148

is that some degree of automation or labor is required to operate it. Also, the step change in reactor feed characteristics that occurs when the flow is switched from one storage tank to another can be a disadvantage unless the operator keeps his knowledge of tank concentrations updated.

Side-Stream Equalization

The side-stream equalization method involves the collection and storage of flow or contaminant concentration surges that result from scheduled dumping operations in the production plant. The surge is diverted to a storage vessel for subsequent processing during slack periods. This procedure is sometimes used to store an alkali waste in a plant for future combining with a waste stream that is normally acidic. The collected alkali could be dispensed into the normally acidic waste stream to reduce consumption and cost of neutralizing reagents. The reverse is often practiced to acidify hexavalent chromium wastes prior to reduction (see Figure 2(c)).

Side-stream equalization for contaminant surges is usually implemented by manually opening diversion valves or directly pumping to the storage tank. The major problem with the system is that either advanced knowledge of the event must be available or online monitoring equipment must be installed. With the possible exception of monitors for flow, conductivity, and pH, on line monitoring is very difficult and expensive to implement and maintain. Probably the best implementation of this type of equalization is as a spill collection tank which can be used to collect and hold spills if and when waste treatment personnel are notified of the spill fast enough to implement the system.

If only flow equalization is required, side-stream equalization can be very effective. It can be implemented either using flow meters connected to pumps and control valves or by a passive system of weirs that diverts excessive flow to a storage tank. The stored water can then be pumped back into the system during low flow. The major advantage of the system is that it requires minimal storage volume and is reliable and relatively simple to implement. The major disadvantage is that it provides little contaminant equalization.

Flow-Through Equalization

The system of flow-through equalization dampens and greatly reduces flow and concentration variations, but does not eliminate them. Typically the system operates on a continuous basis and requires a large tank, mixers, tank baffles, and effluent control devices such as weirs, orifices, control valves, or pumps (see Figure 2(d)). For flow equalization, the tank must be designed to fluctuate in volume in response to influent flow rates. For contaminant equalization, the tank must be large enough to hold the volume which corresponds to the discharge cycle of high or low concentration wastes. The more cycles the tank can hold, the better the equalization achieved. The mixers for contaminant equalization must be sufficient to keep the tank completely mixed and all suspended solids in suspension. If the tank is round, baffles must be installed along the side walls to assure good mixing. The effluent control devices selected will depend on the objective of the equalization. For contaminant equalization, broad crested weirs are frequently used. For simple and reliable flow and contaminant equalization, narrow weirs, proportional weirs, or orifices are used. Pumps or flow control valves are used for maximum flow equalization.

The major advantage of a flow-through equalization system is its simplicity of operation and the continuous nature of its discharge. Flow and contaminant concentration changes do occur, but very gradually. This gradual change usually provides downstream processes such as pH adjustment with adequate time to respond. The major disadvantage of the system is the large tank size generally required.

OPERATIONAL PROCEDURES

The objective of equalization is to limit fluctuations in wastewater flow and/or contaminant concentration to levels that will not adversely affect downstream treatment processes. Equalization can occur on a continuous basis such as in a flow-through system or can be initiated upon demand as with side stream equalization.

Process Monitoring and Operational Criteria

Equalization monitoring takes two forms. First, with the exception of a continuous flow-through system, the wastewater must be continuously monitored for flow and/or contaminant concentration. Monitoring is required to indicate when flow should be diverted to side stream equalization or to determine the fill and draw cycles in batch equalization. Monitoring can be accomplished using either automated on-line equipment or by periodic measurements by the operator. The former is subject to breakdown and the latter is subject to slow response that may completely miss flow or contaminant surges. Therefore, it is necessary to implement both monitoring techniques whenever possible.

It is also essential that a form of monitoring be conducted by production personnel. Whenever production personnel anticipate generating an abnormal flow or contaminant surge, the production personnel must notify waste treatment personnel prior to the event and indicate the time, magnitude, and duration of the the abnormal waste flow. Similarly, if a spill or accidental release of a large quantity of contaminants or water is detected in the production area, then production personnel must notify wastewater treatment personnel immediately. This information is a critical part of wastewater monitoring and is absolutely essential for effective operation of equalization equipment.

The second part of wastewater equalization monitoring is a periodic program to evaluate the effectiveness of the equalization process. As a minimum, this evaluation should occur monthly with batch systems or after any downstream equipment experiences operational problems which could be attributed to poor equalization. To be effective, the monitoring must be set up in a rigorous test program in which influent and effluent flow and contaminant concentrations are measured simultaneously. The frequency of sample collection during the test programs and the duration of the program will depend upon the rate of flow and contamination variability. Typically, these variations follow some pattern and exhibit times of peak and minimum flow and contaminant concentration. To be effective, the monitoring program must collect sufficient grab samples to detect these variations, usually sampling every hour for 24 to 48 hours. In some cases, however, where the variations occur rapidly, more samples will be required. If possible, the days for equalization monitoring should be selected such that the maximum variation in flow and contaminants that has been experienced under normal operating conditions is occurring.

Upon completion of the test, the influent and effluent flow and contaminant concentration should be compared graphically by plotting influent and effluent parameters versus time on the same graph. The peak effluent values should be substantially less than the peak influent values and within the design operating values for downstream equipment. The maximum rate of change for effluent contaminant concentration must also be evaluated when the contaminant concentration can affect chemical feed rates in downstream equipment. Too rapid a change can result in poor performance of equipment such as pH controllers.

Process Control Strategies

For the most part, the operator has little control over the equalization process. For continuous flow-through equalization, control can be exercised by adjusting the pumping rate or orifice openings. For batch equalization processes, little control can be exercised over the equalization process, except for the fill-and-draw cycle which is usually dictated by flow patterns. Side-stream equalization, however, is directly controllable by operators by either adjusting set points on automatic monitoring equipment or by manually diverting the flow based on test results or information from production personnel. Rigid criteria for initiating side stream equalization can not be developed; however, the following facts should be evaluated:

- Sensitivity of downstream equipment to the surge.
- Potential for violating permit conditions if a treatment process upset occurs.
- Reserve capacity in side stream equalization tank for a second more severe surge.
- Likelihood of another event requiring side stream equalization prior to release of current equalization volume.
- Compatability of liquid currently in equalization tank with current waste stream (i.e., a current acidic wastestream should not be diverted to side stream equalization if a cyanide waste is currently stored there. Hydrogen cyanide gas could be produced).

In addition to the monitoring of process operating variables specific to side stream equalization, several general operating and maintenance procedures should be performed routinely on all equalization equipment. These include the following:

- Equalization tanks should be checked monthly for accumulation of solids on the bottom of the tank. When the solids accumulation significantly reduces tank volume, the tank must be cleaned.
- Equalization tanks should be checked weekly for accumulation of floating material. If the floating material interferes with weirs, pump intakes, level indicators, or mixers it must be removed.
- Tanks, baffles, mixers, and pipes should be inspected annually for condition of materials of construction. Corroded or worn parts should be repaired or replaced.
- Monitoring programs to evaluate the performance of equalization should be conducted approximately twice per year or after a treatment process upset that could be linked to inadequate equalization.
- Flow meters, level indicators, and on-line monitors should be calibrated annually or at the manufacturer's specified interval, whichever is less.

- All pumps, mixers, and automated valves should be included in a regular preventive maintenance program.

TYPICAL PERFORMANCE VALUES

Almost any desired level of equalization can be achieved by varying the size and type of equalization equipment. Therefore, performance criteria must be established for individual facilities based on the sensitivity of downstream treatment processes.

TROUBLESHOOTING GUIDE

A troubleshooting guide for operation of the equalization tanks or basin is presented in Table 1. Two major operating problems are considered; these are inadequate contaminant equalization and inadequate flow equalization. For each problem, several probable causes, checks and monitors, and corrective actions are given.

TABLE 1
EQUALIZATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM: 1. Contaminant equalization inadequate.			
1a. Broken or worn mixer impeller.	- Check condition of mixer impeller.	- Broken or worn impellers can dramatically reduce the efficiency of mixing.	- Replace if worn.
1b. Inadequate basin volume caused by solids deposits on the bottom of tank.	- Check for solids accumulations by draining tank or checking tank side wall depth with a pole or similar device.	- Reduced basin volume limits storage capabilities and hence equalization capacity.	- Clean tank and remove solids.
1c. Missing mixing baffles on circular tank.	- Check for condition of baffles on outer wall of circular tanks.	- Baffles must be present to break circular flow patterns which do not contribute to mixing.	- Repair or replace damaged or missing baffles.
1d. Improperly located mixer.	- Check location of mixers; stationary mixers may not have the proper impeller submergence and mixers in deep tanks may be missing draft tubes or multiple impellers. Submerged mixers too close to the surface may vortex and lose efficiency.	- The efficiency of a mixer can be dramatically affected by improper placement.	- Move and adjust as required. Reference manufacturer's recommendations and design specifications.
1e. Inadequate basin size.	- Conduct monitoring program to determine if basin is large enough to contain wastewater flow between low and high flow and/or contaminant cycles. (Note: for good equalization more than one cycle volume may be required).	- Inadequate basin volume limits storage capacity and hence equalization capacity.	- Modify or add tank volume as required.
1f. Inadequate mixing horsepower.	- Check mixing horsepower; check for solids deposition in equalization tank.	- Mixing is directly related to input horsepower.	- Add mixing horsepower as required. Reference manufacturer's recommendations. Typical values range between 0.02 and 0.04 hp/1000 gallons. If gritty material is present, much larger mixing horsepower will be required.

TABLE 1
(Continued)
EQUALIZATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 2: Flow equalization inadequate.			
2a. Flow meters or level indicators that control tank discharge are improperly set or calibrated.	- Check for proper setting and date of last calibration.	- These devices, when incorporated into the system, directly control the flow to and from the equalization basin.	- Calibrate and adjust as required. Reference manufacturers calibration procedure and design specifications for proper setting.
2b. Improper choice of effluent control device.	- Check type of effluent control device.	- Effluent control devices determine the degree of control that can be exercised on effluent flow. Pumps can provide best equalization followed by valves, orifices, proportional weirs, and narrow rectangular weirs.	- Modify discharge device as required.
2c. Leaks around effluent control devices.	- Check for erosion and wear around effluent weirs and orifice plates.	- The amount of flow equalization is directly proportional to the changes in tank volume. Also, in most equalization techniques, as the water level approaches the top of the tank, the effluent flow is dramatically increased to prevent overfilling.	- Repair or replace as required.
2d. Inadequate storage volume.	- Monitor tank level during operation.		- Modify tank design or effluent control devices as required.

SECTION 5

OIL REMOVAL

INTRODUCTION

The sources of oil found in metal wastewater are from cooling operations, cleaning operations, and lubrication. Oil is typically present in wastewater in three forms: free oils, emulsified oils, and soluble oils. Free oils in wastewater are those which rise to the surface of the wastewater due to buoyant forces in a short quiescent period. Emulsified oil is oil dispersed in the wastewater as small droplets which can range in size from 0.1 to 100 microns. Soluble oil is discussed in the next paragraph. A wide variety of oil removal processes is available for removing the free and emulsified forms of oil. The processes include skimming, coalescing, emulsion breaking, flotation, centrifugation, ultrafiltration, reverse osmosis, carbon adsorption, and biological oxidation. The most widely used and conventional treatment processes in the metal finishing industry are gravity separation and skimming, coalescing, emulsion breaking, and flotation. The other processes are not widely utilized at this time and, therefore, are not covered in this manual.

Soluble oils are those organic oils which are dissolved in the wastewater. Soluble oils are generally the lighter, more polar fraction of an oil mixture. Soluble oils are not removable by the techniques described in the preceding and in this chapter. Techniques such as gravity separation, flotation, and emulsion breaking result in removal of free and emulsified oil, but soluble oils remain dissolved in the wastewater. Soluble oils are, in general, biodegradable, so that the most successful treatment for removal of soluble oils is often biodegradation in a biological wastewater treatment system.

Along with the topic of oil removal, the subject of total toxic organics (TTO) must be addressed. The materials which make up the TTO are listed in Appendix B; they are typically degreasing solvents used in the cleaning of metal parts. The waste solvents will contain oils, and will exist as free, emulsified, and soluble oils in the wastewater. The concentration of TTO in metal finishing wastewaters can be greatly reduced by proper handling and disposal of solvents and other organics, especially by segregation of these wastes for contract disposal or reclamation for recycle.

Control and management practices for waste solvents and other components which make up the TTO should be devised to follow resource recovery guidelines. Specifically, development of segregation facilities for these materials should be implemented, and disposal should be by a reputable contractor. The potential for reclamation of the organics should be explored; if reclamation is not feasible then disposal must be performed by a reputable disposal contractor. The importance of proper disposal for materials containing the compounds on the TTO list must be emphasized. Those materials are known to exhibit significant toxicity; severe environmental and human health problems can result from their improper handling or disposal.

THEORY OF OPERATION

The theory of operation for the equipment used to remove free and emulsified oil from wastewater is discussed below.

Gravity Separator

Separator design is based on the specific gravity difference between the dispersed oil globules and the wastewater. The lighter oil globules rise to the wastewater surface and are removed. The oil rise rate is described by Stokes' Law which states the rise rate is directly proportional to the difference in the weight of the oil globule and the wastewater it displaces.

Emulsion Breaking

Emulsified oil is dispersed in wastewater as small droplets. These droplets can range in size from 0.1 to 100 microns. With pure oil and pure water, an oil emulsion is highly unstable since both phases quickly separate and assume a shape having the minimum interfacial area. With oily wastewater, however, an oil emulsion is often formed which is much more stable due to emulsifiers which alter the oil-wastewater interface.

Three common emulsifiers are electrical charge, chemical action, and mechanical assistance. Electrical charge emulsifiers establish a repulsive electrical field at the oil-wastewater interface. This type of emulsifier is normally a negligible cause of stability except for those wastewaters that have a low salt content or dilute oil concentrations. Chemical emulsifiers are materials such as soaps or detergents which cause chemical reactions at the oil-wastewater interface. Mechanical emulsifiers are finely divided colloids such as silt, clay, or metal fines which attach to the oil or are coated by the oil.

Emulsion stability is affected by droplet size, emulsion age, and wastewater viscosity. Smaller droplets are typically more stable. Emulsions generally become more stable with age because the emulsifier is transported to the oil through the wastewater by diffusion. A higher wastewater viscosity generally results in a more stable emulsion since there is more resistance to the movement of small droplets thus reducing the possibility of coalescence.

Coalescing Separator

Coalescing separators work in a similar manner to gravity separators with skimmers except that coalescing separators remove smaller and less bouyant particles. The basic principle of coalescing involves the preferential wetting of a coalescing medium by oil droplets which accumulate on the medium, and then rise to the surface of the solution. The most important requirements for coalescing media are wettability for oil, large surface area, and contact between the oil particles and the coalescing medium.

Air Flotation

In a flotation process, fine gas bubbles are introduced into the wastewater. These gas bubbles attach to oil globules resulting in an aggregate with a specific gravity much less than that of the surrounding wastewater. The attachment of the fine, micron size air bubbles to the oil globules occurs by several mechanisms. The first mechanism is the adhesion of an air bubble to the oil globule or by the direct collision of the air bubble globule. The second mechanism is the trapping of the rising air bubble under an oil globule floc structure. The third mechanism is the adsorption of the air bubble by an oil globule floc. The rise rate of the aggregate is described by Stokes' Law which states that the rate of rise is directly proportional to the difference in weight of the aggregate and the wastewater it displaces. The quantity of gas which can be dissolved in the wastewater is described by Henry's Law, which states that for gases of low solubility the gas mass dissolved in water is directly proportional to its partial pressure.

DESCRIPTION OF EQUIPMENT

Gravity Separators and Skimmers

Gravity separators normally remove free oil and little or no emulsified or soluble oil. The separators are used as primary treatment processes and are particularly applicable for the separation of large quantities of free oil.

Gravity separators range from lagoons with oil retention booms and oil removal devices to tanks with automatic oil skimmers. The American Petroleum Institute (API) has developed design criteria for gravity oil separators. Separators based on these design principles are the most common type of oil separator and are referred to as API separators.

A line diagram of an API separator is presented in Figure 3. The separator includes a trash rack, a forebay with oil skimmer and baffle, an inlet diffusion device, and oil separation channels each with a scraper and oil skimmer. The trash rack removes sticks, rags, stones, and other debris. The forebay distributes the influent. The oil which rises to the surface in the forebay is retained by the baffle and removed by the skimmer. The inlet diffusion baffle reduces flow turbulence and distributes the flow equally over the channel cross sectional area. The free oil rises in the channels, is collected with the scraper, and is removed with the skimmer.

A variation of the gravity separator called the parallel plate separator is also commonly used. It consists of a gravity separator with parallel plates installed in the tank to assure laminar flow conditions. The small distance between the plates also reduces the distance the oil globule must rise, which in turn results in a decrease in the required actual surface overflow rate and hydraulic detention time.

Emulsion Breaking

Chemical emulsion breaking can be accomplished as either a batch process or a continuous process. The emulsion breaking process resembles gravity separation except that concurrent chemical treatment occurs to break up the emulsified oil. The mixture of emulsified oils and water is initially treated by the addition of chemicals to the wastewater. A means of agitation (either mechanical or by increasing the turbulence of the wastewater stream) is provided to ensure that the chemical added and the emulsified oils are adequately mixed to break the oil/water emulsion bond. Finally, the oily residue (commonly called scum) that results rises to the surface and is separated from the remaining wastewater by a skimming or decanting process. The skimming process can be accomplished by any of the many types of mechanical surface skimmers that are presently in use. Decanting methods include

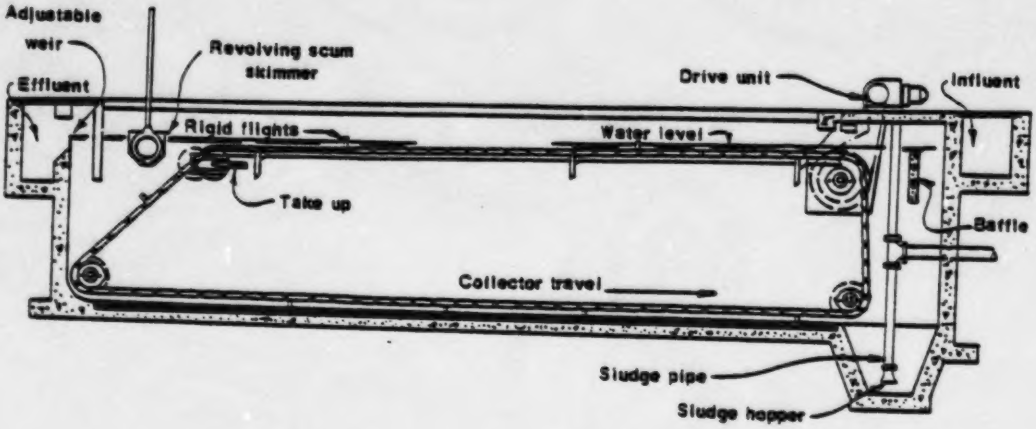

Adjustable weir
Revolving scum skimmer
Effluent
Drive unit
Influent
Rigid flights
Water level
Take up
Baffle
Collector travel
Sludge pipe
Sludge hopper

Figure 3. **API separator.**

removal of the oily surface residue via a technique such as controlled tank overflow or by removal of the demulsified wastewater from the bottom of the tank. Decanting can be accomplished with a series of tap-off lines at various levels which allows the separated oils to be drawn off the top or allows the wastewater to be drawn off the bottom until oil appears in the wastewater line. With any of these arrangements, the oil is usually diverted to storage tanks for further processing or hauling by a licensed contractor.

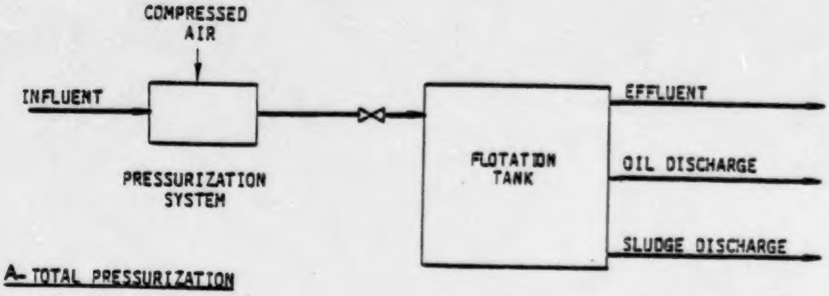
Coalescing

Coalescing also resembles gravity separation, except that the tank is filled with various configurations of coalescing media. The coalescing media can be plates, fibrous media, reticulated polyurethane foams, or loose media so long as they provide a tortuous path for the wastewater. Most media are installed in the form of relatively small diameter cartridges of a standard size, stacked in a parallel position. Orientation may be vertical or horizontal; however, horizontal designs can be more difficult to service since the entire separator vessel must first be drained.

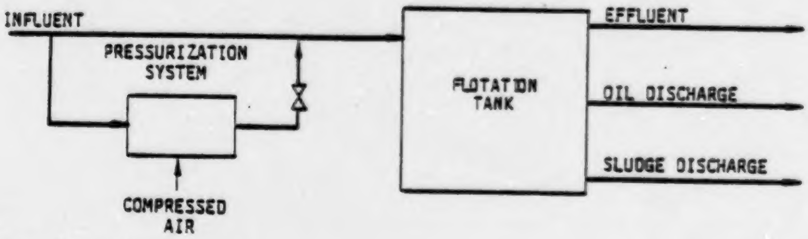
Air Flotation

A variety of flotation methods are commonly used for oil-wastewater separation. The fundamental difference between these methods is the mechanism by which the air is introduced into the wastewater. The two most common methods are the dissolved air flotation (DAF) process and the induced air flotation (IAF) process.

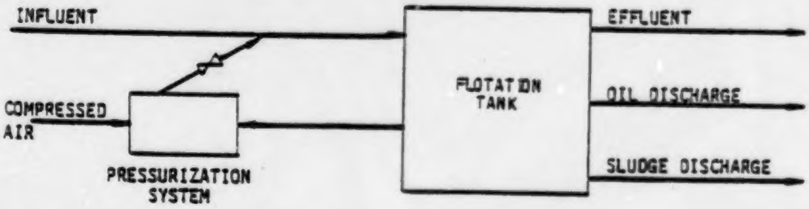
Many variations of the DAF process are used. Three principal variations are full, partial, and recycle operation. Simplified line diagrams of the three principal DAF process variations are presented in Figure 4. These variations differ in the portion of the wastestream which is pressurized and saturated with gas. The full pressurization operation treats the entire influent wastestream. The partial operation treats a portion of the influent wastestream. The recycle operation


COMPRESSED AIR
INFLUENT
PRESSURIZATION SYSTEM
FLOTATION TANK
EFFLUENT
OIL DISCHARGE
SLUDGE DISCHARGE

A- TOTAL PRESSURIZATION


INFLUENT
PRESSURIZATION SYSTEM
COMPRESSED AIR
FLOTATION TANK
EFFLUENT
OIL DISCHARGE
SLUDGE DISCHARGE

B- PARTIAL PRESSURIZATION


INFLUENT
COMPRESSED AIR
PRESSURIZATION SYSTEM
FLOTATION TANK
EFFLUENT
OIL DISCHARGE
SLUDGE DISCHARGE

C- RECYCLE PRESSURIZATION

Figure 4. **Line diagrams of principal DAF process variations.**

treats a portion of the effluent wastestream. A typical recycle system includes a compressed air source, an aeration tank, a feed pump, and a flotation tank. The compressed air is dissolved into the return wastewater at an elevated pressure and stored in the aeration tank. The pressurized wastewater is subsequently mixed with the main wastestream and released to atmospheric pressure in the flotation tank where the dissolved air is released from solution as fine air bubbles, approximately 30 to 120 microns in diameter. The gas bubbles attach to the oil globules and the aggregate rises to the surface and is collected.

The induced air flotation process consists of a multicelled tank, froth launders, a recycle pump, and static air inductors or aspirators. The flow through the cells is in series. The wastewater enters the first cell where air is introduced through the action of an aspirator. The aspirator utilizes recycle process effluent. The air is released in the cell in the form of air bubbles approximately 1000 microns in diameter, somewhat coarser than those in a DAF process. The air bubbles attach to the oil globules and the aggregate rises to the surface and is collected. The remaining wastewater flows through a baffle into the subsequent cells and ultimately out of the system. Alternate IAF separators use different methods to induce air into the wastewater. One system forces air under pressure into the liquid. Another common system induces air into the wastewater through high speed mixers.

DAF separators commonly include a chemical feed system to introduce coagulant aids such as polymers and metal salts, including ferric chloride, alum, and lime. IAF separators almost without exception include a chemical feed system. The chemicals are introduced at a variety of points in the system. Some systems include a separate rapid mix and flocculation chamber.

Skimming Devices

Skimming devices to remove floating oil are an integral part of API gravity, parallel plate, and coalescing separators. Four common skimming devices are the rotary drum, the rotatable slotted pipe, the floating weir, and the belt (or rope) type.

With the rotary drum device, a horizontal drum approximately 0.3 to 0.6 meters (1 to 2 feet) in diameter is partially submerged in the wastestream. Skimming is accomplished as the drum rotates with the flow, picking up a thin oil film which is later scraped off the drum and removed. The depth of submergence is not critical as long as the drum is in contact with the oil layer. A submergence depth of approximately 3 cm (1 inch) is typical. The rotational speed is typically 0.15 to 0.45 m/sec (0.5 to 1.5 ft/sec), but the optimum speed depends upon the amount of oil to be removed and oil viscosity. The device typically results in a recovered oil that is low in water content.

With the rotatable slot device, a horizontal slotted pipe is submerged in the wastestream with the slots normally above the surface. Skimming is accomplished by rotating the pipe such that the slots are submerged, allowing the oil to flow into the pipe and to be removed. This device can result in a recovered oil that may be low or high in water content depending on the amount of care exercised in submerging the slot and adjusting it during the skimming operation.

With a floating weir device, a floating device suspends a horizontal weir in the wastewater channel. The device is weighted such that the weir crest is just above the water surface but below the oil surface. This positioning results in the oil flowing continuously into the weir channel. The recovered oil exits the channel to a discharge point via a flexible hose. The device typically results in a recovered oil high in water content.

With the belt (or rope) device an endless belt is pulled through the wastewater. Skimming is accomplished as floating oils adhere to the belt. After passing through the wastewater, the belt continues on a device located above the liquid level where the recovered oil is squeezed or scraped from the belt and removed. The oil viscosity and attraction to the belt material slows the belt speed and performance. Baffles are commonly used to direct the floating oil to the belt. Belts are typically 0.3 to 0.6 meters (1 to 2 feet) in width. The device typically results in a recovered oil with low water content.

OPERATIONAL PROCEDURES

The objective of oil removal is to reduce free, emulsified, and soluble oil to a level that is acceptable for discharge. This often requires multiple steps that first remove free oil and then emulsified oil by emulsion breaking or air flotation.

Process Monitoring

The performance criterion for evaluating oil removal equipment is effluent total oil concentration. While this parameter provides the overall performance of the system, several other parameters must be measured and incorporated into a regular monitoring program to successfully and consistently operate an oil removal system. These parameters are listed in Table 2.

Of the parameters listed in Table 2, flow should be monitored continuously. Total influent and effluent oil along with pH, suspended solids, and temperature should be measured at regular intervals as specified or after any oil violation or process upset caused by excessive oil. Sampling may be either composite or grab with grab sampling normally preferred for oil measurements. Samples always should be collected in areas of sufficiently high turbulence to entrain free oil. Influent and effluent oils also should be analyzed for free, emulsified, and soluble oil fractions on a monthly basis or after poor performance of oil removal equipment is noted or suspected. More frequent analyses will be required if a plant upset or permit violation is suspected.

Determination of oil content of water is a critical procedure. Procedures for sample collection, storage, and analysis should be performed in strict accordance with established standards. Quality

TABLE 2

OIL REMOVAL
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Flow	Continuously	To determine overflow rate and hydraulic retention time (HRT).
2. Influent total oil	Weekly	To determine mass loading of oil.
3. Influent free, soluble, or emulsified oil	Monthly	To determine mass loading for a particular form of oil.
4. Effluent total oil	Weekly	To determine performance and determine loading to downstream processes.
5. Effluent free, soluble, or emulsified oil	Monthly	To determine performance of the system.
6. Suspended solids	Weekly	
7. Waste oil volume	Daily	To determine quantity of oil to be disposed.
8. Waste sludge volume	Daily	To determine quantity of sludge to be disposed.
9. Temperature	Continuously or per shift	Temperature will affect oil removal performance.
10. pH	Continuously or per shift	pH will affect oil removal performance.

assurance including duplicate analyses and blanks is indispensable. If a violation of permit conditions is detected, sample collection, storage, and analysis procedures should be investigated as part of an assessment of the plant program.

The analysis of samples for total oil content should be conducted according to one of the procedures given in the current edition of "Standard Methods for the Examination of Water and Wastewater".(9) While other techniques are commonly used, they may not be accepted by local regulatory agencies. "Standard Methods", however, does not provide a technique for differentiating between free, emusified, and soluble oil. This differentiation is particularly important when evaluating equipment that is effective in removing one oil classification, but not another. As an example, a gravity separator may appear to be malfunctioning because it is removing only a small fraction of the total oil. If the majority of the oil is free oil, this will be the case. If, however, the majority of the oil is soluble or emulsified oil, the gravity separator may be doing an excellent job removing the free oil that it was designed to remove. A procedure for determining the free, soluble, and emulsified fractions of oils is provided below.

Free Oil--

Place a measured amount of the raw wastewater in a separatory funnel. Shake the sample vigorously and let stand quiescently for approximately two hours. Draw off a portion of the subnatant and determine its oil concentration. The oil measured is the emulsified and soluble fraction. The difference between the total oil concentration and that measured is the free oil concentration of the wastewater sample.

Soluble Oil--

Place a measured amount of the raw wastewater in a separatory funnel and acidify with 10 ml/l of concentrated hydrochloric acid. Next, add 200 mg/lsodium chloride and 200 mg/l diatomaceous earth. Shake vigorously and let stand quiescently for a minimum of eight hours. Filter the mixture through a wet filter paper and measure the oil concentration of the filtrate. The oil concentration measured is the soluble fraction of the wastewater sample.

Emulsified Oil--

The difference between the oil concentration of the emulsified and soluble fraction measured in the Free Oil determination and the oil concentration of the soluble fraction measured in the Soluble Oil determination is the emulsified oil concentration of the wastewater sample.

Example Calculations

Several example calculations are provided below for calculating operating parameters essential to operation of an oil removal system.

Hydraulic Retention Time (HRT)--

HRT is the average length of time wastewater spends in a process tank. Since the removal of oil does not occur instantaneously, it is essential that the wastewater spend a minimum time in the oil separator. The HRT calculation is:

$$HRT = \frac{VOL}{FLOW}$$

where VOL is the liquid capacity of the tank and FLOW is the flow to the separator. Note that the VOL and FLOW must be expressed in similar units such as cubic meters or gallons. As an example, if an oil water separator had a volume of 10,000 m^3 and the flow to the tank was 2500 m^3 per hour the calculation would be:

$$HRT = \frac{10{,}000\ m^3}{2500\ \frac{m^3}{hr}} = 4\ hr$$

Surface Overflow Rate--

Surface overflow rate is the process flow rate divided by the active surface of the area of a clarifier or oil water separator. The result is usually expressed as gallons per square foot per minute and represents the loading on the treatment process with respect to its surface area. The loading can also be expressed as a velocity by converting gallons to cubic meters. This parameter is usually expressed as meters/minute and is used primarily for circular clarifiers and air flotation devices where it represents the average vertical velocity of the water from the submerged center feed well to the surface overflow weirs.

The surface overflow rate is calculated as follows:

$$\text{SURFACE OVERFLOW RATE} = \frac{\text{FLOW}}{\text{SURFACE AREA}}$$

where surface area is the quiesant area of the oil separator excluding influent and effluent weirs and baffles, and flow includes any recycle flow. As an example, if a 10-foot diameter dissolved air flotation oil water separator with a 3-foot diameter center feed well had a flow rate of 80 GPM and a recycle flow rate of 40%, the calculation would be:

$$\text{SURFACE OVERFLOW RATE} = \frac{80 + (0.4 \times 80)}{\frac{\pi \quad (10^2 - 3^2)}{4}} = 1.6 \text{ Gal/ft}^2\text{/min}$$

Air to Solids Ratios (A:S)--

The air to solids ratio is used in conjuction with the air flotation process and represents the ratio of the mass of applied air to the mass of oil plus SS. This ratio is calculated as follows:

$$\text{A:S ratio} = \frac{8{,}990 \text{ SCFM}}{\text{OIL CONC X FLOW}}$$

where OIL CONC is oil concentration in milligrams per liter (mg/L), FLOW is wastewater flow in gallons per minute (gpm), and SCFM is air flow in standard cubic feet per minute (scfm).

As an example the air requirement for a dissolved air flotation tank with an influent oil concentration of 60 mg/L, a flow rate of 50 GPM, and an A:S ratio of 0.05 would be calculated as follows:

$$\text{SCFM} = \frac{0.03 \times 60 \times 50}{8{,}990} = 0.010 \text{ SCFM}$$

Process Control Strategies

Gravity Separation & Skimmers--

Gravity separators typically offer minimal opportunity for operator control. Periodically, the tank must be checked for solids deposits on the bottom of the tank or on the parallel plates if a plate separator is used. Similarly, if any influent and effluent weirs are used they must be periodically checked for trash and debris accumulations which might impede even flow distribution. The weirs must also be checked to assure they are level and to maintain proper liquid depth. The latter is extremely important when slotted pipes are used to remove the collected oil.

The hydraulic retention time and surface overflow rate should also be calculated and compared to equipment design values. Flow to an oil water separator is usually not controllable, but the calculations can indicate if the system is overloaded or requires more equalization. Similarly the temperature and suspended solids should be monitored. Cold temperatures can reduce the rise velocity of oil globules by as much as 50% and high suspended solids can lead to rapid solids accumulation in the tank.

The oil removing or skimming equipment should be checked daily for proper operation and depth of floating oil blanket. Excessive blanket depth, i.e., more than a few inches for most equipment, can rapidly lead to a system failure. Rotary drum and belt skimming devices should be checked at least weekly for drum or belt surface integrity, scraper blade integrity, and tension against drums. Rotating slot skimming devices should be checked as often as required to keep oil blanket depths within safe operating ranges. Care must be taken in operating the slots to prevent excessive water entrainment. The slots must also be checked periodically for levelness and accumulation of trash or debris. Floating weirs must be checked daily to make sure trash is not collecting on the weirs and to make sure the weirs are free floating and properly balanced. Periodically, the flexible hose must be checked for integrity.

Coalescers--

The operation of coalescers is essentially the same as that for gravity separators. The frequency of inspection for solids accumulation and plugging of the coalescers must, however, be on at least a monthly basis.

Emulsion Breaking--

Chemical addition is not a separate unit process for oil-water separation. Rather, it is used prior to or in conjunction with other separation processes. Chemical addition is first used to break or demulsify emulsified oils in the wastewater. The treatment is usually directed toward destabilizing the dispersed oil droplets or chemically binding or destroying any emulsifying agents present.

As previously stated, chemical demulsifying processes include acidification, coagulation, salting out, and demulgation with organic cleaving agents. Acids generally cleave emulsions more effectively than do coagulant salts, but are more expensive. In addition, the resultant wastewater must be neutralized after separation. Coagulation with aluminum or iron salts may be effective and is commonly used. However, the resultant hydroxide sludges may be voluminous and are difficult to dewater. Coagulation with polymer may be effective and is sometimes used. The resultant sludge quantities are smaller than those for metal salts but are sometimes more difficult to dewater. The salting out of an emulsifier may be achieved with the addition of large quantities of an inorganic salt, thereby increasing the dissolved solids content of the wastewater. Organic demulgators may be extremely effective demulsifying agents but are generally very expensive and specialized. Demulgators are normally considered only if they are found to be effective in extremely low concentration due to cost and, in many cases, their toxicity at higher concentrations.

The effectiveness of chemical pretreatment is normally determined with bench scale jar testing. A representative wastewater sample is split into several aliquots. Each aliquot is reacted with a different quantity of the chemical under consideration. After each addition, the aliquots may be flash mixed, flocculated, and quiescently settled and then examined to note any reaction and emulsion breaking and the rate and effectiveness of separation.

One typical procedure for jar tests is that suggested by the Tretolite Division of Petrolite Corporation, in their Industrial Bench Testing Procedures Manual.(11) The procedure is as follows.

1. Secure appropriate sample for testing.
2. Fill one liter beakers to either 500 or 1000 ml mark. Test volume is dependent on volume of sample available and volume required for water quality analysis.
3. Place beakers on paddle mixer and begin mixing at maximum speed.
4. Dose beakers with appropriate chemical(s) and appropriate volumes.
5. Mix on high speed for 1 minute.
6. When chemical additions and 1 minute rapid mix intervals are complete, reduce stirrer speed to slow mix for 1 minute minimum. (Note: Mix times can be varied to more closely duplicate full scale system).
7. Turn mixer off and remove beakers for settling. Settling time is dependent on system and rate of contaminant removal (10-30 minutes should prove adequate).
8. Wipe paddles clean with a paper towel or rag in preparation for the next test.
9. Repeat steps 2-8 until the desired treatment program has been thoroughly investigated.
10. After the chosen settling time has elapsed, sample beakers for appropriate water quality analysis.

The jar test procedure is useful for determining the optimum pH for separation, the most effective coagulant and coagulant aid, the optimum chemical dosage and order of chemical addition, the required rapid and slow mix times, the required settling, and the estimated separation effectiveness.

The pretreatment chemicals may be added directly to a process line or may require separate rapid mix and flocculation chambers. The operation of these chambers is discussed elsewhere in this document under "Chemical Addition Equipment" and "pH Control".

Air Flotation

Air flotation, as compared to gravity separation, has several control mechanisms that are directly under the control of the operator. These include the system pressure, recycle rate, air to solids ratio, and chemical addition rate. The operator also has some control of surface overflow rate and hydraulic residence time. Typically increasing the system operating pressure and air to solids ratio will improve performance. However, care should be taken in increasing these because past a certain air to solids ratio very little improvement is obtained and a considerable amount of energy is expended. As the air to solids ratio is increased it may also be necessary to increase the recycle rate in order to provide sufficient water for air to initially dissolve. However, the increase in recycle rates will increase the surface overflow rate, a situation which can lead to performance degradation if the overflow rate exceeds the system design specifications.

The DAF pocess is typically operated with a 40 to 60 psig pressure, 20 to 50 percent recycle, 1 to 4 gpm/sq ft surface overflow rate, 1 to 2 minute aeration tank detention time, 0.01 to 0.06 air to solids ratio and 20 to 40 minute flotation tank detention time. Typically with the DAF process, compressed air is used as the feed gas because it is relatively inexpensive. However, inert gases are sometimes used instead. For example, nitrogen gas is used to minimize corrosion by keeping iron in solution. The choice of gas can depend also upon the nature of the wastewater and any regulations concerning off-gas removal. The volume of froth layer produced in the DAF process is approximately equal to 0.2 to 2.5 per cent of the influent waste flow.

IAF separators typically use a recycle flow rate of 100 to 400 percent with 5 to 10 minute detention time and result in a froth production rate equal to 1 to 15 percent of the influent flow rate.

When operating air flotation units, pressure gauges and flowmeters should be checked daily for proper readings and calibrated on at least a yearly basis. In addition, any weirs should be checked monthly for trash or debris accumulation and levelness. If scraper arms are used to skim the float, they should be checked monthly for proper submergence, usually around 1/2 to 3/4 inches when water level is at the base of the weirs. They must also be checked for scraper blade integrity and proper seal when crossing the sludge hopper.

TYPICAL PERFORMANCE VALUES

The performance of oil removal equipment is extremely dependent upon the distribution of oil between the free, emulsified, and soluble forms. Gravity oil separators typically have produced an effluent with a total oil concentration between 50 and 100 mg/L. However, gravity separators with an emulsion breaking pretreatment step give typical performance ranges from less than detectable to 40 mg/L of effluent oil. Coalescers should provide slightly better performance than gravity separators. Limited information regarding their performance indicates that an effluent of 1 to 50 mg/L of oil can be achieved (includes units with and without emulsion breaking).

DAF and IAF separators typically produce effluents of equal quality. A flotation separator, preceded by a gravity or parallel plate separator, typically produces an effluent with an oil concentration less than 20 mg/L. When used without pretreatment, the flotation separator can produce an effluent with an oil concentration of 25 to 100 mg/L.

TROUBLESHOOTING GUIDE

A guide for troubleshooting the oil removal process is presented in Table 3. Six problem areas are noted; all the problem areas deal with either excessive oil in the aqueous effluent or excessive water in the collected oil phase. In many cases a detailed analysis of the oil emulsion breaking treatment will be required to correct the problem. Careful sampling, jar test evaluations, and oil analyses are required to define the problem and investigate corrective actions.

TABLE 3
OIL REMOVAL TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Gravity separator has high effluent oil concentration.			
1a. Flowrate too high.	- Check peak and average flow rate, hydraulic retention time (HRT), and surface overflow rate and compare manufacturer's recommendation and design criteria.	- Separators are designed to achieve quiescent conditions in the oil-water separation zone. Excessive flow promotes turbulence.	- Decrease flow rate; add more oil-water separator capacity; increase equalization if peak flow is excessive.
1b. Emulsified and/or soluble oil present.	- Monitor the free, emulsified, and soluble oil concentration entering and leaving the separator.	- Gravity separator is effective for free oil only.	- Troubleshoot Step 6; install emulsion breaking equipment if not present; control sources of soluble oil.
1c. Short circuiting of tank occurring.	- Check influent and effluent weirs and baffles for plugged, broken, or missing units. Check weirs for for levelness.	- When short circuiting occurs the oil does not have time to separate from the water.	- Clean, repair, replace, or adjust as needed.
1d. Separator tank filled with solids.	- Drain tank and inspect or rod with a pole to detect the presence of solids or sludges on the bottom of the tank.	- As the solids collect in the tank the HRT is decreased and the oil does not have sufficient time to separate from the water.	- Clean and remove all solids and sludges.
1e. Excessive floating oil blanket in separator tank.	- Monitor effluent for free oil and visually inspect for floating oil in effluent.	- If floating oil layer becomes too deep it can extend down to treated water effluent port.	- Adjust oil skimming devices as required.
1f. Change in influent characterization.	- Check viscosity, temperature, and density of oil-water solution and collected oil. Compare to original design conditions and manufacturer's recommendations.	- If process changes result in changes in the density and viscosity of the oil and water, the design requirement for gravity separators can change.	- Modify separator design as required.

TABLE 3
(Continued)
OIL REMOVAL TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 2: Gravity separator has a very high water content in collected oil.			
2a. Holes or cracks in collection slots.	- Inspect and monitor for water flow when oil is not being removed.	- Treated water can contaminate collected oil.	- Repair as required.
2b. Poor operation of oil collection slot or tilted floating weir which allows water to enter.	- Monitor operation of collection slot. Inspect floating weir for levelness and presence of trash in weirs.	- Treated water can contaminate collected oil.	- Adjust equipment or instruct operators as required.
2c. Floating weir has improper ballast resulting in weir floating too low in water.	- Check distance between bottom of weir and oil-water interface.	- If water too close to the bottom of the weir, wave action caused by wind or hydraulic surges can cause water to enter the weir.	- Clear weir to remove heavy deposits; adjust weir as specified by manufacturer.
2d. Slot oil collectors are located too near the oil water interface.	- Check distance between slot and oil water interface during nonskimming operation.	- If water too close to the bottom of the slot, wave action caused by wind or hydraulic surges can cause water to enter the slot.	- Adjust as required (may require adjusting of an effluent weir opposed to adjusting slot).
OPERATING PROBLEM 3: Coalescer has high effluent oil concentration.			
3a. Coalescers clogged or broken.	- Drain tank and inspect.	- For proper performance oil must come in contact with coalescing plates and proper velocities must be maintained.	- Clean and repair as required.
3b. pH of oil-water solution different from design or normal operating condition.	- Monitor pH.	- pH can affect surface properties of oil droplets and their ability to coalesce.	- Adjust pH to design or normal operating conditions.
3c. See Step 2.	- See "Troubleshooting Gravity Separators"	- See "Troubleshooting Gravity Separators"	- See Step 2.

TABLE 3
(Continued)
OIL REMOVAL TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 4: Air flotation unit has high effluent oil concentration.			
4a. Inadequate dissolved air being supplied.	- Monitor oil concentration; monitor air flow; determine air:solids (oil) ratio.	- Insufficient air being supplied to float the mass of oil present.	- Adjust as required; typical range is 0.01 to 0.06 pounds of air per pound of oil.
4b. Inadequate recycle flow.	- Check recycle flow rate.	- Recycle flow is often essential to provide enough water to dissolve the required air.	- Adjust as required; see design and manufacturer's recommendations. Typical values range from 20 to 50% recycle.
4c. Inadequate delivery pressure.	- Check delivery pressure and check calibration of pressure gauge.	- Insufficient pressure can result in the air not dissolving in the water.	- Adjust as required; see design and manufacturer's recommendations. Typical values range from 40 to 60 psig.
4d. Inadequate hydraulic retention time (HRT).	- Monitor flow rate; check tank for accumulation of solids; calculate HRT.	- Short HRT's do not allow sufficient time for solids to separate.	- Decrease flow rate; troubleshoot "Equalization"; clean tank. Typical values are 20 to 40 minutes.
4e. Excessive surface overflow rate.	- Monitor flow rate and calculate surface overflow rate.	- Large overflow rates can carry solids out of the tank and break foam.	- Decrease flow rate; troubleshoot "Equalization". Typical values are 1 to 4 gpm/sq ft.
4f. Short circuiting of DAF occurring.	- Check effluent weirs for plugging and levelness. Check influent baffles.	- Short circuiting can result in inadequate detention times.	- Clean and adjust weirs as required.
4g. Skimmer not removing solids fast enough.	- Inspect skimmers for broken scapers, proper submergence in the water, poor seal along the edges or sludge hopper; check speed.	- Air flotation foam breaks with time and can cause reentrainment of oil particles.	- Repair and replace damaged scapers as required. Adjust submergence and rotational speed as required.
4h. Improper chemical addition (where applicable).	- Check chemical feed pumps for proper operation, setting, and calibration.	- Inadequate chemical conditioning can result in significantly reduced performance of air flotation equipment.	- Clean, repair, and adjust as required.

TABLE 3
(Continued)
OIL REMOVAL TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
	- Perform jar test to optimize type dosage and pH of chemical conditioning agent. The nature of the waste may have changed.	- Inadequate chemical conditioning can result in significantly reduced performance of air flotation equipment.	- Adjust chemical addition equipment as required.
	- If polymer is being used check initial dilution and placement of polymer addition.	- Proper mixing of polymer and waste essential. Polymers must be initially diluted to 0.1 to 0.5% for proper mixing to occur. Polymer can be sheared by injecting it upstream of a centrifugal pump.	- Adjust initial polymer dilution procedures as required. Change polymer addition point to assure adequate mixing prior to downstream release in air flotation tank.
OPERATING PROBLEM 5: Float from air flotation unit contains excessive water.			
5a. Leak in float collection hopper.	- Check hopper with skimmer arm turned off. If water enters hopper, leak is present in hopper or top of hopper located below water surface.	- Water contaminating concentrated oil.	- Repair or adjust as required.
OPERATING PROBLEM 6: Emulsion breaking is not converting all emulsified oil to free oil.			
6a. Poor mixing between oil and chemicals.	- Check mixing equipment for worn mixers, missing baffles, and adequate horsepower (See Table 1).	- Proper mixing of conditioning agent and waste water is essential for conditioning agents to be effective.	- Repair and replace as necessary.
6b. Improper conditioning agent or dosage.	- Perform jar test to determine optimum conditioning agent, dosage, and pH.	- Waste characteristics determine optimum conditioning agent, dosage, and pH.	- Adjust chemical addition equipment as required.
6c. Fluctuating or improper pH.	- See "pH Troubleshooting Guide."	- Most emulsion breaking techniques are pH-sensitive.	- See "pH Troubleshooting Guide."

SECTION 6

CYANIDE OXIDATION

INTRODUCTION

Cyanide (CN^-) is used in the metal finishing industry to keep metal ions (zinc, copper, etc.) in the electroplating solutions from precipitating. Cyanide is typically added as sodium cyanide (NaCN) or hydrocyanic acid (HCN). Added either way, the cyanide ion is both highly toxic and soluble. Furthermore, if the pH of cyanide containing waste drops below 7, hydrogen cyanide gas (HCN) which is extremely poisonous will be evolved.

THEORY OF OPERATION

The most frequently employed method for treating cyanide waste is cyanide destruction by chlorination. Other oxidants such as ozone are used also. During the oxidation process, cyanide may be either partially oxidized to a less toxic form, cyanate (CNO^-), or completely oxidized to carbon dioxide (CO_2) and nitrogen (N_2). This corresponds to what is commonly referred to as "one-stage" and "two-stage" treatment respectively. Both stages can be accomplished using various forms of chlorine including chlorine gas dissolved in water, sodium hypochlorite (NaOCl), or calcium hypochlorite ($Ca(OCl)_2$). Acid hydrolysis is also used for destroying cyanate.

Chlorine Oxidation

The first stage of the cyanide destruction is chlorine oxidation of cyanide to cyanate. The equation for this reaction is:

$$Cl_2 + NaCN + 2NaOH \longrightarrow NaCNO + 2NaCl + H_2O$$

This reaction has an intermediate step that first converts chlorine gas to the hypochlorite ion (OCL^-) which then reacts with the cyanide. Because the oxidation reaction depends upon the presence of the hypochlorite ion, it is necessary to perform this reaction at a pH greater than 8.5. This requires that caustic (NaOH) be added to ensure that a pH greater than 8.5 is maintained at all times, and to maintain it during the reaction which consumes two caustic molecules for each cyanide ion oxidized. If the pH is allowed to decrease below 7.0, the reaction will stop and the highly toxic gas, cyanogen chloride, will be evolved. The overall reaction of cyanide to cyanate is both time and pH dependent. At a pH of 10.0 or higher, oxidation of cyanide to cyanate is accomplished rapidly and completely if oxidation periods of 30 to 120 minutes are maintained.(13)

The second stage of the cyanide destruction process is chlorine oxidation of cyanate to nitrogen and carbon dioxide which is then converted to bicarbonate and carbonate ions. This reaction depends upon the presence of hypochlorous acid (HOCl) for an oxidant, as opposed to one stage oxidation which requires the hypochlorite ion. Therefore the pH must be less than 8.5, normally in the range 8.0 to 8.5. The relationship between the cyanate oxidation reaction, pH, and required detention time is displayed in Figure 5. However, for actual plant operations a detention time of 60 minutes is recommended.(13) The chemical formula for cyanate oxidation is:

$$3Cl_2 + 6NaOH + 2NaCNO \rightleftharpoons 2\ NaHCO_3 + N_2 + 6NaCl + 2H_2O$$

As previously stated, the chlorine required for cyanide oxidation can be added to the system in several forms including chlorine gas, sodium hypochlorite solution, and calcium hypochlorite solution. Chlorine gas is quite soluble in water and when dissolved in water, chlorine hydrolyzes rapidly to form hypochlorous acid (HOCl) and/or hypochlorite ion (OCl^-) depending upon the pH. The effect of pH on the distribution

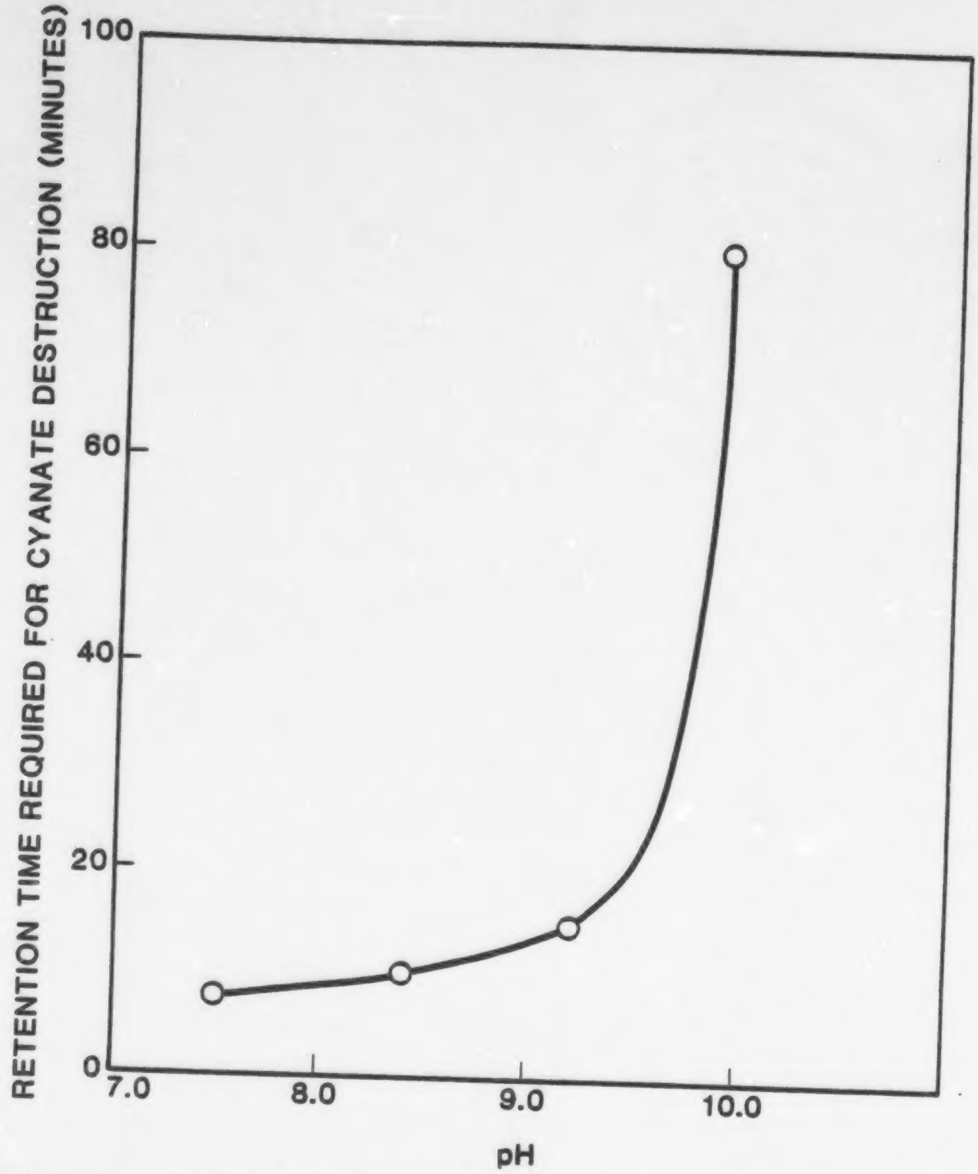


Figure 5. **Destruction time required for Cyanate vs pH.**

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of hypochlorous acid and hypochlorite ion in water at two different temperatures is shown in Figure 6. When dissolved in caustic and water (pH>8.5), chlorine will form the hypochlorite ion (OCl^-). The dissolution reaction for the hypochlorite ion is

$$Cl_2 + 2NaOH \longrightarrow 2Na^+ + OCl^- + Cl^- + H_2O.$$

It can be seen from the equation that one molecule (or one kilogram mole) of chlorine gas will require two molecules (or two kilogram moles) of caustic and will yield one molecule (or one kilogram mole) of hypochlorite ion (OCl^-). The ratio of chlorine gas to caustic is important because caustic and chlorine are generally added at a controlled ratio. Note that we generally add materials to be reacted by weight (kg or lb), although reactions occur by the molecule or mole basis. The mass in kilograms divided by the molecular weight gives the number of kilogram moles.

The main advantage of using chlorine gas is that the chemical cost is the lowest of the three oxidizing agents. However, there is a great disadvantage because chlorine gas is difficult to handle and is toxic. Therefore, the choice of using chlorine gas becomes a trade-off between materials handling-safety and cost.

Sodium hypochlorite (NaOCL) requires no preparation and can be used directly as an oxidizing agent. The main advantage in using sodium hypochlorite is that it is relatively easy and safe to handle and use. The use of calcium hypochlorite [$Ca(OCl)_2$] requires that, for best results, it be dissolved into solution before introduction into the oxidizing reaction. When calcium hypochlorite is not dissolved in water first, increased quantities of sludge will be produced.

Acid Hydrolysis

A second method for destruction of cyanate is acid hydrolysis. Acid hydrolysis is accomplished by lowering the pH to a value of 2 or 3 by adding sulfuric acid. Five minutes reaction time is required to destroy the cyanates.(13) Two disadvantages of this procedure are that

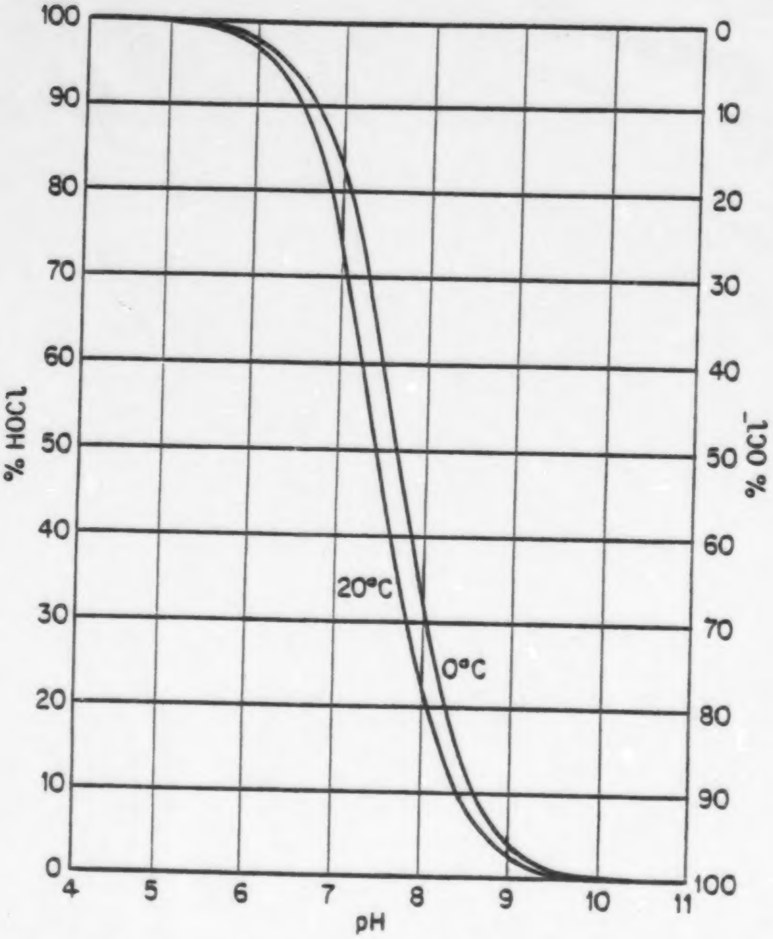

Figure 6. **Distribution of HOCL and OCL.**

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the pH must be lowered to 2 to 3 with acid; then after hydrolysis, the pH has to be raised again to pH 6 to 9 for discharge. This requires significant volumes of neutralizing agents (both acid and caustic) which increases the total dissolved solids of the wastewater. Furthermore, if incomplete destruction of cyanides occurs in the first stage for any reason, hydrogen cyanide gas will be released when the acid is applied.

DESCRIPTION OF EQUIPMENT

Typical equipment for cyanide treatment consists of reaction vessels, mixers, pH controllers, and chlorinators. These can be operated in a batch or continuous flow mode. Either mode can be used to achieve single stage cyanide oxidation (the conversion of cyanide to cyanate) or two stage oxidation (the conversion of cyanide to CO_2 and N_2). A typical system for a continuous two-stage oxidation unit is shown in Figure 7. It includes two reaction vessels, two automatic pH controllers, two mixers, and a chlorinator with dual control circuits to control independently the chlorine dose for each reaction vessel based on reactor oxidation reduction potential (see Section 7, Chromium Reduction). When only single-stage cyanide reaction is required, the second reaction vessel is deleted from the system. The advantage of single-stage operation is reduced chemical and capital costs as compared to two-stage operation. The disadvantage of single stage oxidation of cyanide to cyanates is that cyanates are somewhat toxic. However, they are much less toxic than cyanides, but in some areas discharge of cyanates may not be allowed.

Batch cyanide oxidation equipment basically resembles the single-stage continuous equipment except that it is operated in a batch mode. This mode of operation requires either an intermittent flow or multiple tanks. In either case, increased operator involvement is required to fill and draw the tanks and to readjust the pH controller between the first and second stage when two-stage oxidation is practiced. For these reasons, batch treatment is seldom practiced when average flows exceed 15 GPM.

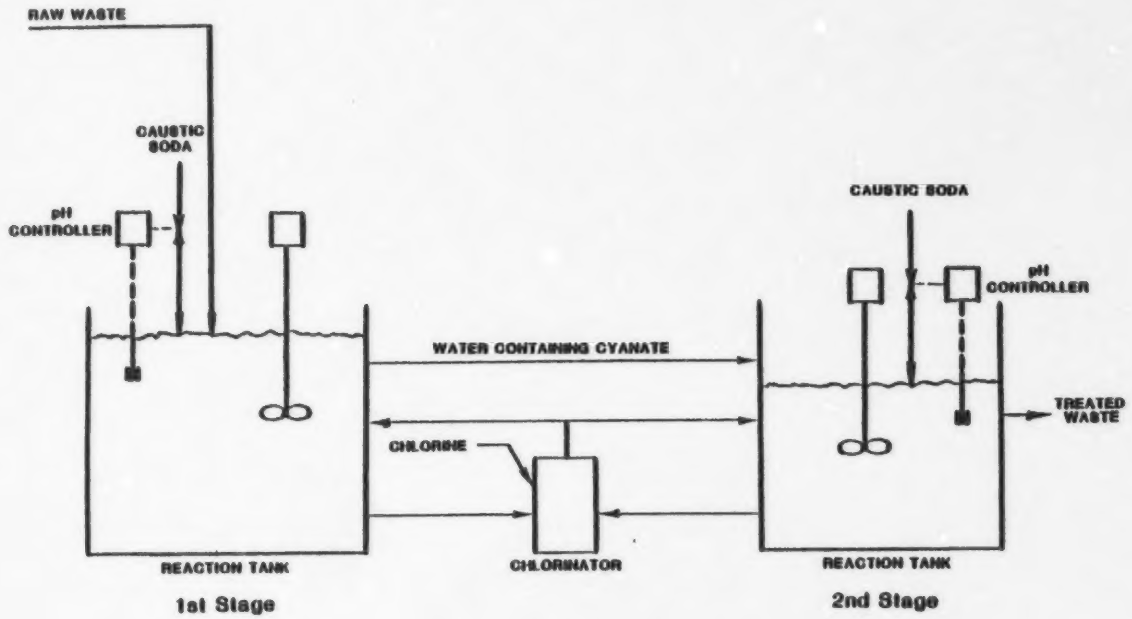
RAW WASTE
CAUSTIC SODA
pH CONTROLLER
WATER CONTAINING CYANATE
CHLORINE
CHLORINATOR
REACTION TANK
1st Stage
CAUSTIC SODA
pH CONTROLLER
TREATED WASTE
REACTION TANK
2nd Stage

Figure 7. **Two-stage cyanide destruction.**

OPERATIONAL PROCEDURES

To control the operation of the cyanide destruction process, the operator should conduct the necessary process monitoring, perform any control calculations needed, and understand the process control strategies.

Process Monitoring

The main performance criterion used to evaluate the cyanide reduction process is the reactor effluent concentration of cyanide in one stage oxidation or the second reactor effluent concentration of cyanide and cyanate in two stage oxidation. While these parameters provide the overall performance, many other parameters should be measured and incorporated into a regular monitoring program to successfully and consistently operate a cyanide reduction process. These parameters are listed in Table 4. For continuous treatment systems, flow, pH, and oxidation reduction potential (ORP) are normally recorded on a continuous basis. The probes for these units should be calibrated weekly with daily calibration preferable. The cyanide in the process influent and the cyanide and free chlorine in each reactor vessel effluent should be measured daily using a composite sample for cyanide and a grab sample for chlorine. These measurements are required to verify adequate treatment and to establish a working relationship between free chlorine, ORP, and cyanide destruction. The effluent temperature and suspended solids should also be measured on a daily basis to provide an understanding of how these parameters affect efficiency of destruction.

In addition to the above standard, monthly or quarterly analyses of the treatment plant influent for interfering agents should be performed. These agents either cause an excessive use of chlorine or form cyanide complexes that cannot be oxidized by chlorine. These agents include cuprous, nickelous, ferrous, and ferric ions. The presence of cuprous ion in cyanide wastes produces an apparent interference to the destruction of cyanides. The cuprous ion exerts a chlorine demand of 0.56 lbs of available Cl_2 per lb of cuprous copper present. Therefore, at least

TABLE 4

CYANIDE REMOVAL
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Reactor Temperature	Daily	To measure temperature.
2. Flow	Continuously	To determine HRT and to adjust chemical dosages.
3. Influent Cyanide Concentration	Daily	To determine destruction efficiency.
4. Effluent Cyanide Concentration	Daily	To measure any residual.
5. Effluent Cyanate Concentration	Daily	To determine loading to downstream processes.
6. Chlorine Concentration	Daily	To measure excess chlorine.
7. Reactor pH	Continuously	To control caustic addition.
8. Reactor ORP	Continuously	To control chlorine addition.
9. Effluent Suspended Solids Concentration	Daily	To determine loading to downstream processes.
10.Reactor Sludge Volume	Daily	To determine treatment chemical requirements and mixing effectiveness.

an additional 0.56 lbs of available Cl_2 has to be used in the oxidation of cyanides to account for this chlorine demand.

The above discussion of cuprous ions also holds true for nickelous ion which exerts 2.24 lbs of available chlorine demand per lb of nickelous ion. This 2.24 lbs/lb represents an excess of 3.7 times the theoretical amount required for the oxidation of nickelous ion to nickelic ion. This excess has been found experimentally to be necessary to eliminate the nickelous interference.

Ferrous and ferric ions present in wastewaters that contain cyanide can react with cyanides to form a complex that is only slightly oxidizable by chlorine.

Example Calculations

Hydraulic residence time (HRT) represents the average length of time wastewater spends in the chemical reaction tank assuming complete mixing of the reactor. Since the oxidation of cyanide is not an instantaneous reaction, it is essential that the wastewater remain in the reaction tank for at least the minimum recommended HRT.

The HRT calculation is:

$$HRT = \frac{VOL}{FLOW}$$

where:

VOL = the volume of liquid in the tank
FLOW = the flow to the reactor.

Note that VOL and FLOW must be expressed in similar units such as cubic meters or gallons. As an example, if a cyanide oxidation vessel had a volume of 6000 gallons and the flow to the tank was 8000 gallons/hour the calculation would be:

$$HRT = \frac{6000\ GAL}{8000\ GAL/HR} = 0.75\ HRS$$

Process Control Strategies

The principal operating strategies for process control of both one and two stage cyanide oxidation are pH, ORP (which controls the chlorine addition), mixing, and HRT. Of these variables the operator has ready control of pH and ORP. The HRT, while having a major impact on the process, is established by the wastewater flow rate and the reactor design, and therefore the operator has little control for continuous-flow systems. However, for batch systems the operator has control of the HRT.

For first stage oxidation, the ORP should be maintained between 350 and 400 mV(12) for a pH between 9.5 and 10. Typically, this will result in nearly complete oxidation of cyanide in 30 to 120 minutes.(13) In general, increasing ORP will decrease the required reaction time (HRT). Similarly, increasing pH to a value of 10 will decrease required reaction time (HRT). Above a pH of 10, no improvement in performance is achieved. Therefore, operating at a pH above 10 will only result in increased caustic consumption and a high strength wastewater that must be neutralized.

For two stage treatment the first stage is operated as described above. However, the second stage is typically operated at a pH between 8 and 8.5 and the ORP is maintained at approximately 600 mV. Increasing the ORP will decrease the reaction time but unlike first stage oxidation as the pH is decreased reaction time is also decreased. In practice, however, the pH is seldom allowed to decrease below 8.0 for two reasons. First, if incomplete oxidation of cyanides occurred in the first stage for any reason, extremely toxic hydrogen cyanide gas could be released when the pH is dropped to 7 or below. Secondly, if the pH were to drop to 5 or below, nitrogen trichloride, an explosive compound, could be produced.

In addition to the above parameters several other items should be checked by the operator on a routine basis. These include reactor mixing, reactor bottom for solids deposition, the reactor effluent for suspended solids, solids production, temperature, and the condition of chemical feed equipment.

Mixing is important for four major reasons. Firstly, good mixing is essential to assure good contact between cyanide and the oxidizing agent, chlorine. Secondly, good mixing is required to minimize short circuiting which can cause the actual HRT to be much shorter than the calculated HRT. Thirdly, if inadequate mixing is present in the first stage oxidation, cyanide precipitates which resist oxidation can form. Lastly, inadequate mixing can result in solids settling out in the reaction vessel, thereby reducing its effective volume and HRT.

To assure good mixing the operator should periodically inspect the basin. The operator should also check influent and effluent structures for integrity. The influent and effluent structures should be located at opposite ends of the reaction vessel. Circular tanks should also be equipped with mixing baffles along the side walls. The operator either should occasionally drain the tank or rod the side walls to make sure solids are not being deposited in the tank. The operator also should inspect the mixer. The impeller should be checked for proper submergence and wear. The mixer should also be checked for proper horsepower (see Table 5) especially if poor mixing occurs and no other cause can be found.

The reactor water temperature also should be periodically checked. While wastewater temperature cannot usually be controlled it can affect reaction rates and general performance of the system. By monitoring temperature, variations in performance can sometimes be understood. Similarly, suspended solids concentrations should be monitored. A significant increase in solids across a first stage reactor can indicate inadequate mixing and can result in cyanides being carried through as precipitates.

TABLE 5

HORSEPOWER REQUIREMENTS FOR MEDIUM AGITATION

Vessel Volume (gal)	Horsepower
100	0.27
1000	2.3
10,000	12
100,000	80

TYPICAL PERFORMANCE VALUES

The oxidation of cyanide by chlorine can achieve efficiencies of 99% or greater with respect to cyanides not complexed with iron (ferrous and ferric ions), giving effluent cyanide concentrations for cyanide not complexed with iron typically ranging from non-detectable to 10 ppb. For total cyanide, the concentrations typically run from non-detectable to 100 ppb.

TROUBLESHOOTING GUIDE

A troubleshooting guide for operation of the cyanide oxidation process is presented in Table 6. The operating problem areas are threefold -- high cyanide in effluents, high cyanates in effluents, and solids accumulation in the reactors. The high cyanide-cyanates problems usually involve chemical phenomena or equalization; the problem of solids accumulation is primarily physical in nature and is resolved by adequate reactor mixing.

TABLE 6
CYANIDE OXIDATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: High cyanide in the effluent.			
1a. Improper or fluctuating reactor pH.	- See "pH Control Troubleshooting Guide."	- Cyanide oxidation is pH sensitive. pH levels less than 9 dramatically reduce the reaction rate.	- See "pH Control Troubleshooting Guide."
1b. Inadequate equalization.	- See "Equalization Troubleshooting Guide."	- Flow surges can cause erratic performance of pH control equipment and wash the cyanide through the treatment process before it has had time to react.	- See "Equalization Troubleshooting Guide."
1c. Improper or fluctuating ORP.	- Check ORP set point. - Check calibration and condition of ORP probe. - Check chemical feed equipment for proper operation.	- Low chlorine dosages can prevent the destruction of cyanides (ORP should be between +350 to + 400 mV in first stage destruction).	- Clean, calibrate, and adjust chlorine addition equipment and ORP controller as required.
1d. Inadequate mixing.	- Check condition of mixer impeller. - Check all mixing baffles including influent, effluent, and sidewall baffles on circular tanks. - Check motor RPM and horsepower. (See Table 5).	- Inadequate mixing can result in formation of solids containing cyanide which resist cyanide destruction. It can also result in reactor short circuiting, poor pH control, and poor contact between chlorine and cyanides.	- Repair and adjust as required.
1e. Inadequate residence time.	- Check reaction vessel for solids accumulation. - Monitor reactor flow and calculate HRT.	- Accumulation of solids in the reaction vessel and excessive flow can reduce hydraulic residence time, thus leaving inadequate time for the reaction to occur.	- Clean reactor. - Reduce flow.

TABLE 6
(Continued)
CYANIDE OXIDATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
1f. Significant quantities of ferrous or ferric ions present.	- Monitor wastewater for presence of iron ions.	- Iron cyanide complexes are formed in presence of ferrous and cyanide ions. They are very stable and resistant to most treatment techniques.	- Identify source of ferrous and ferric ion and eliminate .
OPERATING PROBLEM 2: High cyanates in the effluent.			
2a. Improper or fluctuating reactor pH.	- See "pH Control Troubleshooting Guide."	- Cyanate oxidation is pH sensitive. pH levels between 8.0 and 8.5 should be maintained.	- See "pH Control Troubleshooting Guide."
2b. Inadequate equalization.	- See "Equalization Troubleshooting Guide."	- Flow surges can cause erratic performance of pH control equipment and wash the cyanate through the treatment process before it has had time to react.	- See "Equalization Troubleshooting Guide."
2c. Improper or fluctuating ORP.	- Check ORP set point. - Check calibration and condition of ORP probe. - Check chemical feed equipment for proper operation.	- Low chlorine dosages can prevent the destruction of cyanides (ORP should be around +600 mV for second stage cyanide destruction).	- Clean, calibrate, and adjust chlorine addition equipment and ORP controller as required.
2d. Inadequate mixing.	- Check condition of mixer impeller. - Check all mixing baffles including influent, effluent, and sidewall baffles on circular tanks. - Check motor RPM and horsepower. (See Table 5)	- Inadequate mixing can result in reactor short circuiting, poor pH control, and poor contact between chlorine and cyanates.	- Repair and adjust as required.

TABLE 6
(Continued)
CYANIDE OXIDATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
2e. Inadequate residence time.	- Check reaction vessel for solids accumulation. - Monitor reactor flow and calculate HRT.	- Accumulation of solids in the reaction vessel and excessive flow can reduce hydraulic residence time, thus inadequate time for the reaction to occur.	- Clean reactor; reduce flow.
OPERATING PROBLEM 3: Solids accumulate in reactors.			
3a. Inadequate mixing.	- Check condition of mixers, mixer horsepower, RPM of mixers if variable speed mixers are used and condition of side wall baffles if circular tanks are used.	- Inadequate mixing can result in the formation of precipitatants that contain cyanides. Precipitated cyanides resist oxidation.	- Repair and replace equipment as required.
3b. Grit or metal filings present in wastewater.	- Inspect solids in tanks to determine their nature.	- Gritty solids such as metal filings cannot be kept in suspension unless very high mixing horsepower is provided.	- Install grit chamber or similar grit collection system upstream of the process.

SECTION 7

CHROMIUM REDUCTION

INTRODUCTION

Chromium is used in the metal finishing industry as a corrosion inhibitor either in the chromate form, CrO_4^{-2} ion, or as the dichromate form, $Cr_2O_7^{-2}$ ion. As either ion, chromium exists with a valence of +6 (hexavalent). At this valence chromium is both toxic and soluble. Reduction of chromium from the +6 valence state to the +3 valence state and subsequent precipitation of the trivalent chromium is the most common method of chromium removal from wastewater. Other methods include ion exchange and carbon adsorption.

THEORY OF OPERATION

Reduction is a chemical reaction in which one or more electrons are transferred to the chemical being reduced (e.g., +6 chromium) from the chemical initiating the transfer (i.e., reducing agent). There are several reducing agents that can be used to supply electrons to the hexavalent chromium to reduce it to trivalent chromium. These reagents include metallic iron, ferrous sulfate, sulfur dioxide, and various forms of sulfites such as sodium sulfite, sodium bisulfite, and sodium metabisulfite. The chemical reactions for chromium reduction by the most commonly used reagents are shown below.

Sulfur Dioxide:

$$Na_2Cr_2O_7 + 3SO_2 + H_2SO_4 \longrightarrow Cr_2(SO_4)_3 + Na_2SO_4 + H_2O$$

Sodium Sulfite:

$$Na_2Cr_2O_7 + 3Na_2SO_3 + 4H_2SO_4 \longrightarrow Cr_2(SO_4)_3 + 4Na_2SO_4 + 4H_2O$$

Sodium Bisulfite:

$$Na_2Cr_2O_7 + 3NaHSO_3 + 2.5\ H_2SO_4 \longrightarrow Cr_2(SO_4)_3 + 4h_2O + 2.5\ Na_2SO_4$$

Sodium Metabisulfite

$$Na_2Cr_2O_7 + 1.5\ Na_2S_2O_5 + 2.5\ H_2SO_4 \longrightarrow Cr_2(SO_4)_3 + 2.5H_2O + 2.5\ Na_2SO_4$$

The choice of reducing agent depends on the overall process options and localized cost conditions. Sodium metabisulfite offers stability and dry chemical feed capabilities as advantages over the use of bisulfite. A disadvantage of using sulfur dioxide is the potentially hazardous situation that exists when sulfur dioxide is stored and handled. Advantages of sulfur dioxide include ease of automatic control and its lower chemical cost. Ferrous sulfate reduction has been reported to have the advantage of effectiveness which is independent of pH. However, it has also been pointed out that ferrous sulfate produces four times the quantities of sludge produced through the use of sulfur dioxide or bisulfite.

DESCRIPTION OF EQUIPMENT

Chromium reduction can be achieved in either the batch or continuous-flow mode. Both modes require a reaction vessel, mixer, pH controller, ORP controller, and chemical addition equipment (See Figure 8). Batch systems are usually limited to small flows and are operated manually by employees who monitor the pH and ORP and add chemicals as required. The advantages of batch treatment are that the level of hexavalent chromium discharge and complexity of automation are both low. Continuous-flow systems, however, must have automated chemical feed systems that are capable of maintaining proper pH and ORP. The advantage of continuous-flow treatment is that the manpower needs are low.

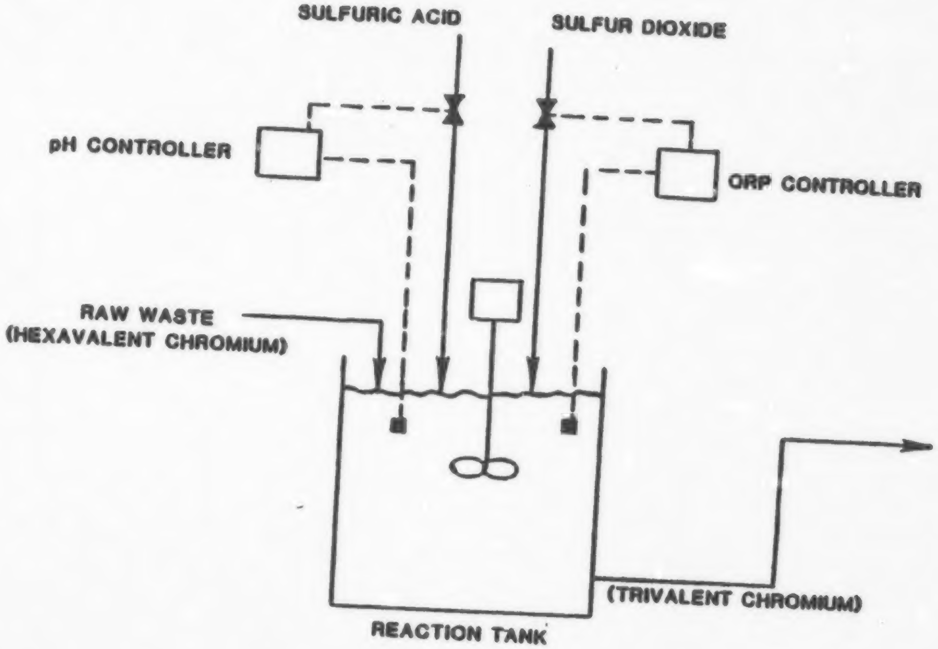
SULFURIC ACID
SULFUR DIOXIDE
pH CONTROLLER
ORP CONTROLLER
RAW WASTE
(HEXAVALENT CHROMIUM)
(TRIVALENT CHROMIUM)
REACTION TANK

Figure 8. **Hexavalent chromium reduction with sulfur dioxide.**

OPERATIONAL PROCEDURE

The objective of chromium reduction is to convert hexavalent chromium to trivalent chromium. This procedure is crucial because hexavalent chromium is highly toxic to aquatic organisms and is a known carcinogen. It is also very soluble in water in its hexavalent state and is very difficult to remove without first converting it to the trivalent state. Trivalent chromium is less toxic than hexavalent chromium and can be removed readily from wastewater by standard chemical precipitation between pH levels of 7 and 9.

To control the operation of hexavalent chromium reduction processes, the operator should conduct the necessary process monitoring, perform any control calculations needed, and understand the process control strategies or variables.

Process Monitoring

The major parameter used to assess the efficiency of chromium reduction processes is the concentration of hexavalent chromium (chromium +6). The main performance parameters used to monitor the operation of the chromium (+6) reduction process are the flow and the concentration of hexavalent chromium in the reactor effluent. While these parameters provide the overall performance, many other parameters must be measured and incorporated into a regular monitoring program to successfully and consistently operate a chromium reduction process. The parameters which should be monitored for chromium reduction are listed in Table 7.

For continuous-flow treatment, flow, pH, temperature, and ORP are normally recorded whenever the process is in operation. Effluent trivalent chromium and hexavalent chromium concentrations are typically measured using 24 hr composite samples. The remaining analyses should be performed on a regular but less frequent basis, typically weekly.

TABLE 7

CHROMIUM REDUCTION
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Reactor Temperature	Continuously	To understand changes in reaction rate for $Cr^{(+6)}$ to Cr^{+3}.
2. Flow	Continuously	To determine HRT and to adjust chemical dosages.
3. Influent Hexavalent Chromium	Weekly	To determine removal efficiency.
4. Effluent Hexavalent Chromium	Daily	To determine any residual Cr^{+6}.
5. Effluent Trivalent Chromium	Daily	To determine loading to downstream treatment.
6. Reactor pH	Continuously	To control acid addition.
7. Reactor ORP	Continuously	To control sulfite addition.

Example Calculations

One example calculation is provided below for calculating operating parameters essential to operation of a chromium reduction process.

Hydraulic Residence Time (HRT) is the average length of time wastewater spends in the chemical reaction tank. Since the reduction of chromium is not an instantaneous reaction, it is essential that the wastewater spend a minimum time in the reaction tank. The HRT calculation is:

$$\text{HRT} = \frac{\text{VOL}}{\text{FLOW}}$$

where

VOL = the volume of liquid in the tank and
FLOW = the flow to the reactor.

Note that VOL and FLOW must be expressed in similar units such as cubic meters or gallons. As an example if a chromium reduction tank had a volume of 5000 gallons and the flow to the tank was 2500 gallons/hour the calculation would be:

$$\text{HRT} = \frac{5000\ \text{gal}}{2500\ \frac{\text{gal}}{\text{hr}}} = 2\ \text{hr}$$

Process Control Strategies

The primary operating strategies which control the performance of a chromium reduction process are the reducing agent used, the reactor HRT, and the reactor pH and ORP. The selection of reducing agent is typically made during the design of the facility, and the HRT is a function of the reaction volume and wastewater flow, both of which are usually beyond the control of the operator. This leaves pH and ORP as the primary process control variables over which the operator has control.

Operator control of the chromium reduction process is usually exercised by first adjusting the pH of the reactor based on the HRT. The relationship between the reactor HRT and the required pH for chromium reduction using sulfur dioxide is given in Figure 9. It is important to understand the significance of Figure 9. From Figure 9 it can be seen that for a 20-minute retention time, a pH of 3.0 or less is required to achieve complete reduction of chromium. If the retention time of the system were to decrease from 20 minutes to 10 minutes because of an increase in the flowrate, complete reduction of chromium could still be achieved by decreasing the operating pH from 3.0 to 2.5 or less. However, if the pH remained at 3.0, incomplete chromium reduction would occur. From Figure 9 it can be observed that if the retention time is 50 minutes, a pH of 4.0 or less is sufficient.

The remaining primary control parameter is ORP. ORP is a measure of the preponderance of easily oxidizable or reduceable substances in a wastewater sample. The importance to the operator is knowing whether there is large quantity of reducing substances that may have an immediate and very high demand for oxygen. Sulfide and sulfite are examples of such substances. This measurement, although not specific, is instantaneous.(14) The oxidation-reduction potential is measured in a galvanic cell consisting of a reference electrode (e.g., calomel) and an indicating electrode of a highly noble metal (e.g., platinum or gold). The calomel electrode is the cathode and the inert platinum or gold electrode is the anode. The anode is made of a highly noble metal so that the potential for its oxidation is less than that of any oxidizable solution components. The anode thus is a site of the oxidation of solution constituents but ideally is not affected itself.

Oxidation-reduction potential measurements in natural waters and wastewaters are difficult to interpret. The only potentials that will register in the ORP cell are those from species that can react at the indicator electrode surface - these are called electroactive species. In natural waters only a few reactions proceed at the electrode surface.

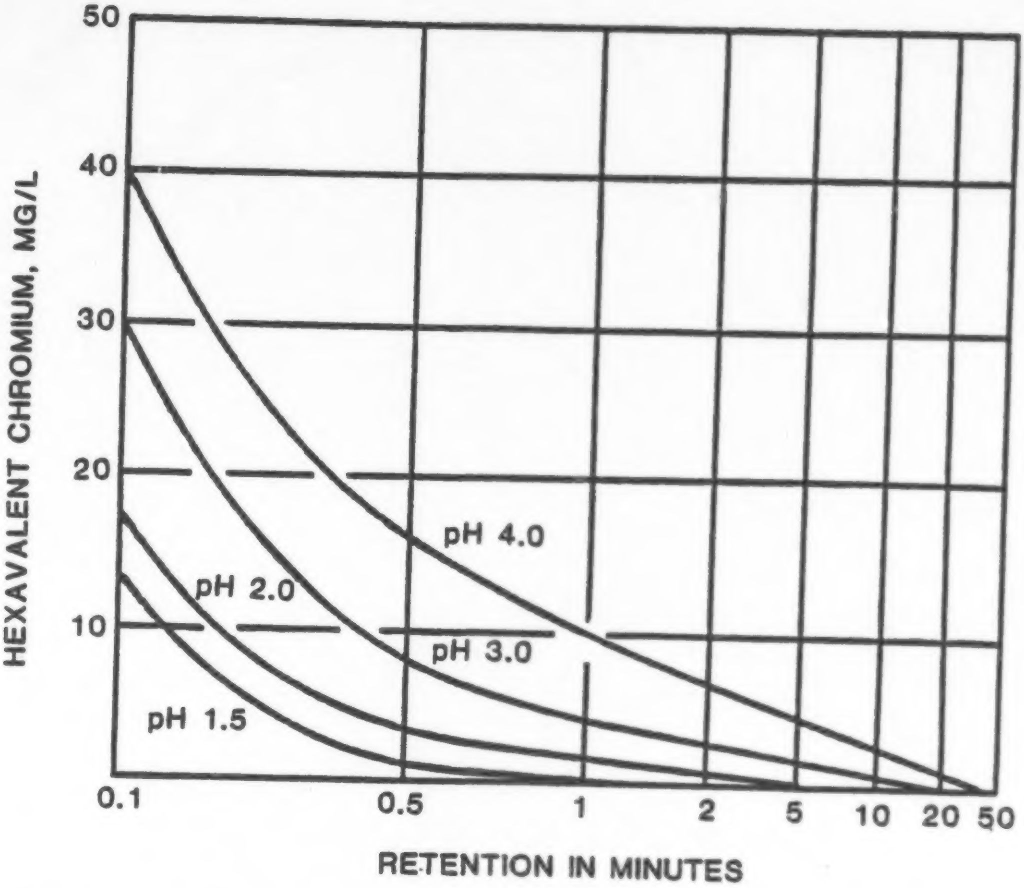

Figure 9. **Relationship between hexavalent chromium, pH, and retention time for sulfur dioxide.**

All the important redox reactions involved in the nitrogen cycle, the sulfur cycle, and the carbon cycle are not completed at the indicator electrode in an ORP cell. At best, too, the voltage reading produced by an ORP cell is a reflection of many reactions - it is a "mixed potential" and its value is difficult if not impossible to interpret in any fundamental chemical terms. Moreover, when an ORP electrode combination is immersed in a water the voltage reading will vary with time, usually falling from the initial reading obtained. This behavior is due to the general process of polarization and of "poisoning" of the indicator electrode surface by the accumulation of oxidation products on the surface of the electrode.(15)

Despite all of these limitations ORP measurements have been used widely in metal finishing treatment systems where, if they are treated as indices or "black box measurements" rather than fundamental indicators of a specific chemical environment, they can be of qualitative use.(15)

The ORP of a chromium reduction reactor is controlled by the amount of reducing agent added. The ORP set point for the chromium reduction is somewhat dependent upon the pH and the ions present in solution. An ORP value of +300 mv at a pH of 2.3 will normally be satisfactory for chromium (+6) reduction. The relationship between pH and ORP for sodium bisulfite is presented in Figure 10. If inadequate chromium reduction occurs under these circumstances the operator should try decreasing the pH and/or increasing the ORP operating level.

Several other factors affect the operation of the chromium reduction process to a lesser extent and should be checked any time poor performance or excessive chemical use is encountered. Among these factors are mixing, temperature, and mass loading. Rapid and good mixing of the wastewater, acid, and reducing agent is important to ensure efficient use of chemicals. Overfeeding of chemicals is usually required if mixing is inadequate. Furthermore, solids can settle out in the reaction tank if mixing is inadequate, a situation which reduces the

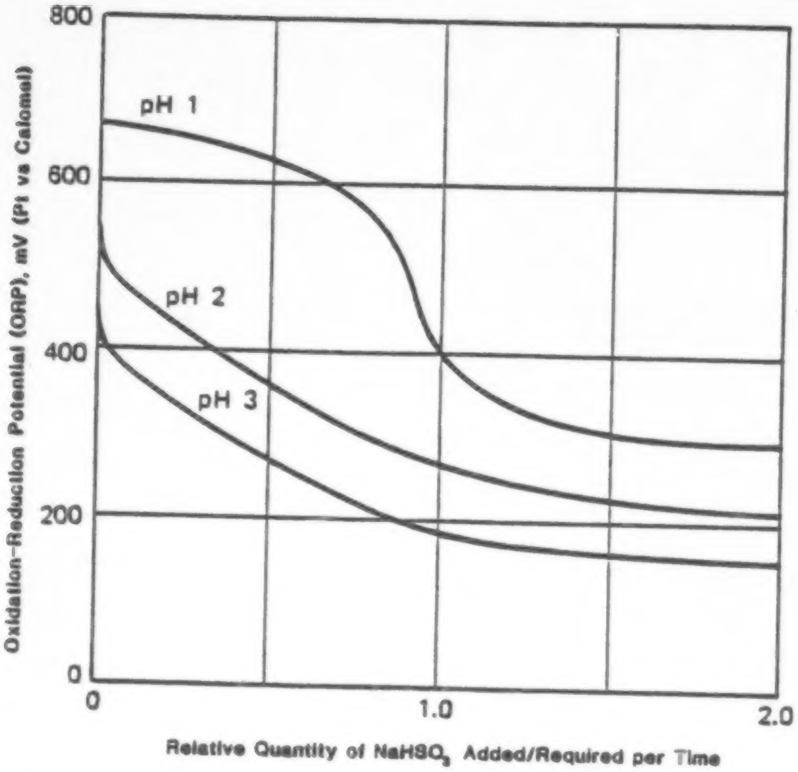

Figure 10. **Relationship between ORP, sodium bisulfite required, and pH.**

effective volume of the tank which in turn reduces the HRT. When the HRT is decreased, lower operating pH levels and hence increased chemical usage are required.

To ensure that good mixing is maintained several items must be checked periodically by the operator. Among the items are the following:

- Check mixer impeller for wear and proper location with respect to the drive shaft and the tank.
- Check baffles for wear and proper placement. All circular tanks should have baffles along the outer vertical wall and most other tank walls should have some form of influent or effluent baffle to prevent short circuiting.
- Check tank bottom to determine if solids are accumulating. This is usually accomplished either by draining the tank or by rodding the sides to determine water depth versus tank depth.
- Check mixer horsepower. Typical mixer horsepower ratings are given in Table 5.

The effect of temperature on the performance of chromium reduction sometimes can be very significant. Temperature primarily affects reaction rates and, to a lesser extent, mixing. The operator has little control over temperature, but periodically monitoring the temperature may enhance understanding of slightly poorer performance during periods of cold weather. If large temperature swings occur it may be necessary to decrease reactor pH or increase ORP levels. It also should be noted that temperature changes can have dramatic effects on instrument calibration. Any time significant temperature changes occur, pH and ORP meters should be recalibrated.

Significant increases in the mass loading of chromium to a treatment process can result in temporary upsets and increased chemical usage. Hexavalent chromium loading in the reactor effluent also directly relates to the plant discharge of chromium which often is expressed as a mass per time (i.e., lb/day or kg/day). For these reasons the influent and effluent loadings should be calculated periodically to gain insight into process performance.

TYPICAL PERFORMANCE VALUES

Hexavalent chromium concentrations in the effluent from chromium reduction processes range from 0.009 to 0.045 mg/L. Most values, however, are less than 0.02 mg/L in a well-operated system.

TROUBLESHOOTING GUIDE

A troubleshooting guide for the chromium reduction process is presented in Table 8. The major operational problem in chromium reduction processes is incomplete reduction of hexavalent chromium which results in a significant concentration of Cr^{+6} in the reactor effluent. The causes of incomplete reduction may be physical (short-circuiting, sampling and analysis errors, etc.) or chemical (incorrect pH, ORP, etc.).

TABLE 8
CHROMIUM REDUCTION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Cr^{+6} concentration too high.			
1a. Sampling or analytical error.	- Check collection procedure with operator and check with lab to ensure proper reporting of results.	- Error could be with data.	- Recalculate new concentration and make sure hexavalent chromium is to be measured, not total chromium.
1b. Retention time too short to complete Cr^{+6} destruction.	- Calculate retention time versus time shown in retention time/pH graph (see Figure 9).	- Retention time may be insufficient for complete chromium destruction.	- Increase retention time by decreasing the flowrate; or decrease pH.
1c. Shortcircuiting in reaction vessel.	- Inspect mixing regime of tank. Look for dead spots, sludge accumulation, and inlet and outlet shortcircuiting.	- Shortcircuiting will decrease the effective retention time.	- Shortcircuiting may be reduced by installing baffles, increasing pumping action of mixer, or installing inlet and outlet baffles.
1d. Improper pH.	- Check desired pH setting of meter versus retention time.	- Setpoint pH may be too high for given retention.	- Select lower setpoint pH.
	- Check calibration of pH meter.	- Meter may be out of calibration.	- Recalibrate.
	- Check operation of acid addition equipment (pumps, valves, and storage tank).	- Failure to achieve desired pH could be caused by insufficient acid, inoperable pumps or valves, or malfunction in control system.	- Correct as necessary.

TABLE 8
(Continued)
CHROMIUM REDUCTION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
1e. Improper ORP.	- Check desired ORP setting.	- Settings range from +200 mV to +400 mV with an average of +300 mV.	- Establish new setpoint ORP.
	- Check calibration of ORP meter.	- Meter reading may not represent actual ORP reading.	- Recalibrate meter.
	- Check location of probe.	- If probe is not located at effluent, then probe is not reading effluent ORP.	- Locate probe at effluent.
	- Check operation of chemical addition system.	- Failure to achieve desired ORP could be caused by insufficient chemical supply, inoperable pumps or valves, or malfunction in control system.	- Correct as necessary.
1f. Hydraulic surges to reaction vessel.	- Monitor flow rate over time and check plant production personnel.	- Evaluate whether flow rates reduce retention time such that complete chromium reduction is not accomplished.	- Equalize flow by decreasing rate of chromium waste discharge from process tanks.

SECTION 8

pH CONTROL

INTRODUCTION

Control of pH is a fundamental process for virtually every metal finishing wastewater treatment system. It is the crux of wastewater metal precipitation that pH be maintained within a narrow range to achieve optimum metal removal. Close pH control is required also for chromium reduction, cyanide oxidation, and possibly for emulsion breaking of oils. Furthermore, it may be required to post-neutralize the treated wastewater to assure that the discharge is within regulatory limits. Because of the number of treatment processes that require pH adjustment, a metal finishing wastewater treatment system may contain several pH control steps, and may include pH control within selected plant processing units.

THEORY OF OPERATION

The parameter pH is a measure of the hydrogen ion (H^+) concentration in a water or wastewater solution. It is calculated as the negative logarithm (base 10) of the hydrogen ion concentration, which means that for each drop in pH of one unit a tenfold increase in the H^+ ion concentration takes place. This means that when the hydrogen ion concentration increases, the pH decreases and the water becomes more "acidic." Likewise, when the hydrogen ion concentration decreases, the pH increases and the waste becomes more "basic" or "alkaline." When the pH is 7 the waste is neither acidic or basic and is considered neutral.

The adjustment of pH requires that, to lower the pH of the wastewater, some chemicals which release H^+ ions must be dissolved in the water. The most common chemicals used in waste treatment are sulfuric acid (H_2SO_4), hydrochloric acid (HCl), and nitric acid (HNO_3). Similarly, to raise the pH, some chemical that reacts with the H^+ ion from solution must be added. The most common chemicals for raising pH are caustic (NaOH), lime (CaOH), and soda ash (Na_2CO_3). The lime and caustic work by releasing a hydroxide ion (OH^-) which reacts with an H^+ ion to form water, H_2O. The soda ash works by reacting with one H^+ ion to form the bicarbonate ion (HCO_3^-) or with two H^+ ions to form $H_2O + CO_2$.

Whenever pH levels are changed, the concept of buffering must be discussed. Buffering is the resistance of a solution to pH changes. This resistance is typically low at pH levels close to 7 and very high for pH levels less than 4 or greater than 10. The resistance, however, is very dependent on the chemicals present in the wastewater.

The best way to determine buffering is with a titration curve. A titration curve is generated by taking a sample of wastewater and gradually adding the acid or base and recording the pH after a small amount of the reagent is added and well mixed. An example titration curve is plotted in Figure 11. It is constructed by plotting the volume of pH-adjusting chemical added versus the pH of the waste sample after mixing with the adjusting chemical. In the example displayed in Figure 11, it can be seen that the first 40 ml of the caustic (NaOH) solution raised the pH from approximately 1 to 2. The next 20 ml of the caustic solution, however, raised the pH to approximately 11.5. In terms of buffering the first segment of the curve is referred to as highly buffered. A large quantity of caustic solution was required to make a small change in pH. The second segment is referred to as poorly buffered. Only a small addition of caustic solution was required to make a large change in pH.

The practical effects of buffering on pH adjustment will be discussed in later sections of this chapter, but from this example it is

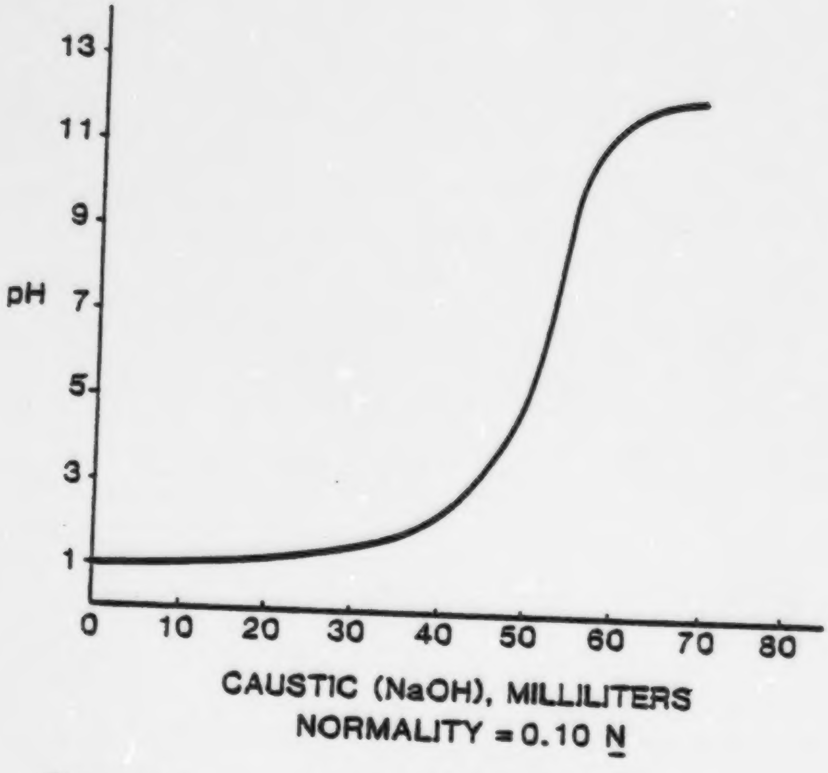

Figure 11. **A sample titration curve.**

easy to see that a pH of 2 could easily be maintained. A pH of 7, however, is difficult to maintain because a very small addition of caustic solution can make a very significant change in pH.

DESCRIPTION OF EQUIPMENT

The pH adjustment process typically consists of a reaction tank, mixer, pH control system, and reagent feed system. The pH adjustment process may either be a batch or a continuous flow system. In a batch system, wastewater is added to the reaction tank; then chemical reagents are added to adjust the pH; and finally the solution is discharged to the subsequent treatment units. Control of the steps in the batch pH adjustment process can either be automatic or manual.

In continuous flow systems, wastewater is continuously entering the reaction vessel. The flowrate can either be constant, if equalization is provided, or variable. Often pH adjustment is accomplished in more than one reaction vessel. This is especially true when the set point is located on a poorly buffered segment of the titration curve. The first tank will adjust the pH close to the set point using a relatively large chemical feed system. The second tank will then use a small metering pump to fine tune and adjust the pH to the set point level. Alternately, a single tank can be used in conjunction with a low and high rate chemical feed system. When the deviation between the set point and the actual pH is large, the high rate system is used. When the difference is small, the low rate system is used to fine tune the adjustment. This system is primarily used for batch operations.

Automatic control of chemical reagent addition is mandatory for continuous systems. There are various methods for providing control of the pH adjustment process. These methods include feedback, feedforward, and feedforward-feedback control techniques and several types of control signal generators. The method best suited for a particular application is dependent upon characteristics of the waste, hydraulic retention time of the reaction vessel, mixing, reaction lags, and other factors.

The common pH control techniques employed today are the feedback, feedforward, and feedforward-feedback control concepts. Feedback control bases the chemical feed rate on the difference or error between the set point pH and the measured pH. Thus, a feedback system solves the pH control problem by trial and error. An example of a feedback control system is shown in Figure 12. The major advantage of this system is that, because it operates by trial and error, the system does not need to know the flow and pH of the influent. It is also relatively insensitive to changes in the titration curve. A disadvantage to feedback control is its susceptibility to oscillatory response, which results from an inherent time lag in the response. This time lag is referred to as "dead" time and is the time required to deliver the chemicals to the wastewater, mix the chemical with the wastewater, and for the appropriate chemical reactions to occur. This time lag means that after a controller initiates a control action, it does not see the results of that action until the "dead" time has elapsed. If the control action were excessive because of poor buffering, a rapid change in flowrate, or excessive "dead" time, the set point can be overshoot before the controller realizes it. It can then overreact to the overshoot and the pH can begin to oscillate around the set point. This oscillation can result in unacceptable performance and/or excessive chemical use.

A feedforward control system does not experience the oscillation problem associated with feedback control. A feedforward system operates by measuring the flow and pH of the wastewater before it reaches the pH adjustment tank. It takes this information and computes the necessary chemical addition based on titration information that has been programmed into the controller. A schematic of a feedforward system is shown in Figure 13. The primary advantage of the system is that it is not susceptible to the problems encountered by feedback control. The system, however, is dependent upon having the ability to predict the buffering of the incoming wastewater. This means that the system can only be used on wastewater streams which have buffering capacity and titration curves that do not vary with time. This is usually a severe restraint when controlling pH. The system is also susceptible to gradual drifts in effluent pH because of cumulative controller error

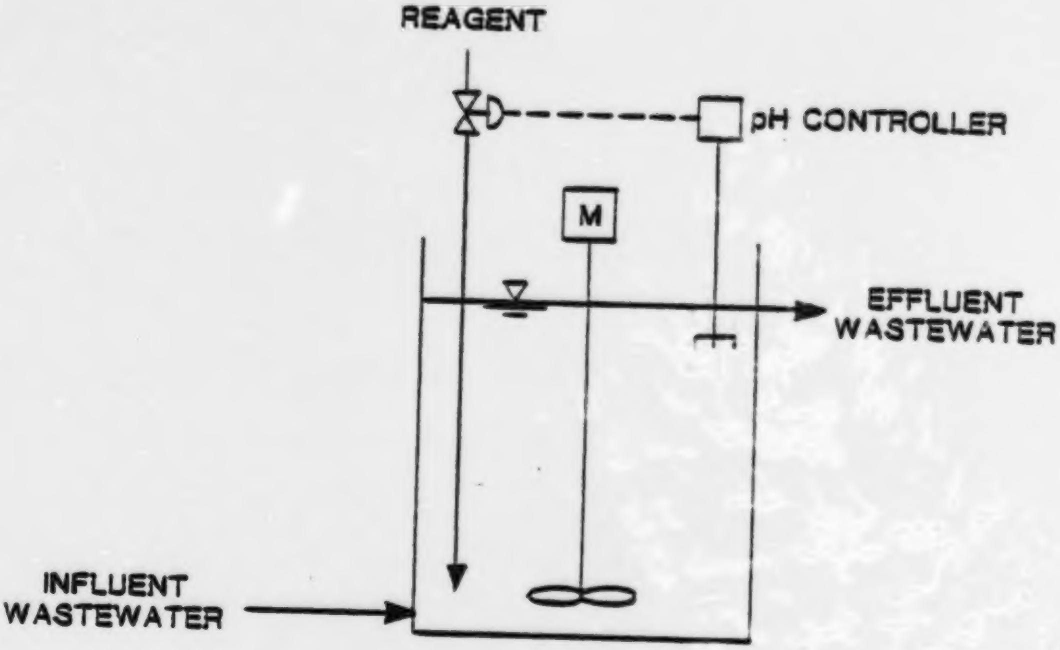
REAGENT
pH CONTROLLER
M
EFFLUENT WASTEWATER
INFLUENT WASTEWATER

Figure 12. **Feedback mode of pH control.**

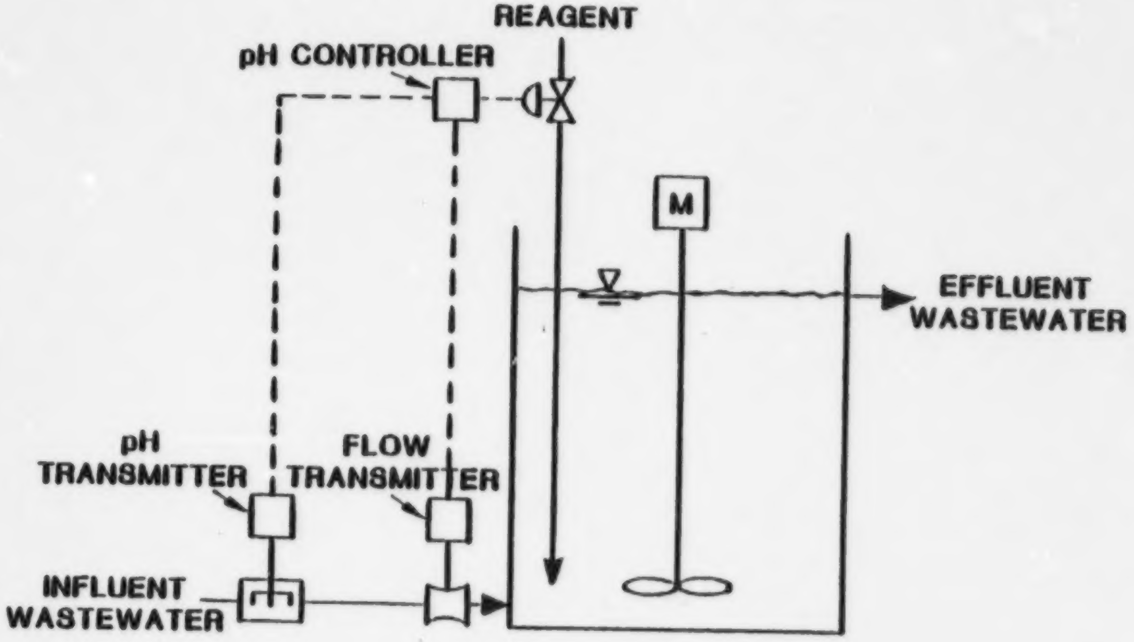
REAGENT
pH CONTROLLER
M
EFFLUENT WASTEWATER
pH TRANSMITTER
FLOW TRANSMITTER
INFLUENT WASTEWATER

Figure 13. Feedforward mode of pH control.

which the controller has no way of detecting because it does not sense the pH of the wastewater after adjustment.

The most common utilization of feedforward control is in conjuction with feedback control. This is referred to as feedback-feedforward control. This configuration is shown in Figure 14. The intent is that the feedforward counteracts most of the problems caused by rapid changes in buffering and flowrate and the feedback provides residual control and setpoint tracking. The advantage of this configuration over feedforward control is better pH control for variable strength and buffering of the influent waste. The above control systems can incorporate several different types of control signal generators that are responsible for directly controlling chemical addition equipment. These include on-off signal controllers, proportional signal controllers, integral signal controllers, differential signal controllers, and programmed signal controllers. These controllers can be used individually or, as is more often the case, in combination. A brief desciption of the controllers and their applicability is provided below.

On-off Controllers

On-off controllers simply generate control signals that turn chemical feed equipment on and off based upon the reactor pH. This type of controller is typically slow and unable to achieve fine pH control. Use of on-off controllers is normally confined to batch operation where speed is not critical, and to multiple stage continuous systems where on-off control is used in the first stage which is designed for gross pH adjustment, not set point tracking.

Proportional Controllers

Proportional controllers generate control signals proportional to the difference between the set point pH and the actual pH (error). This means that as the error grows the chemical addition increases to compensate. This technique is quick and effective for linear regions of a titration curve. However, it does have one drawback in continuous flow

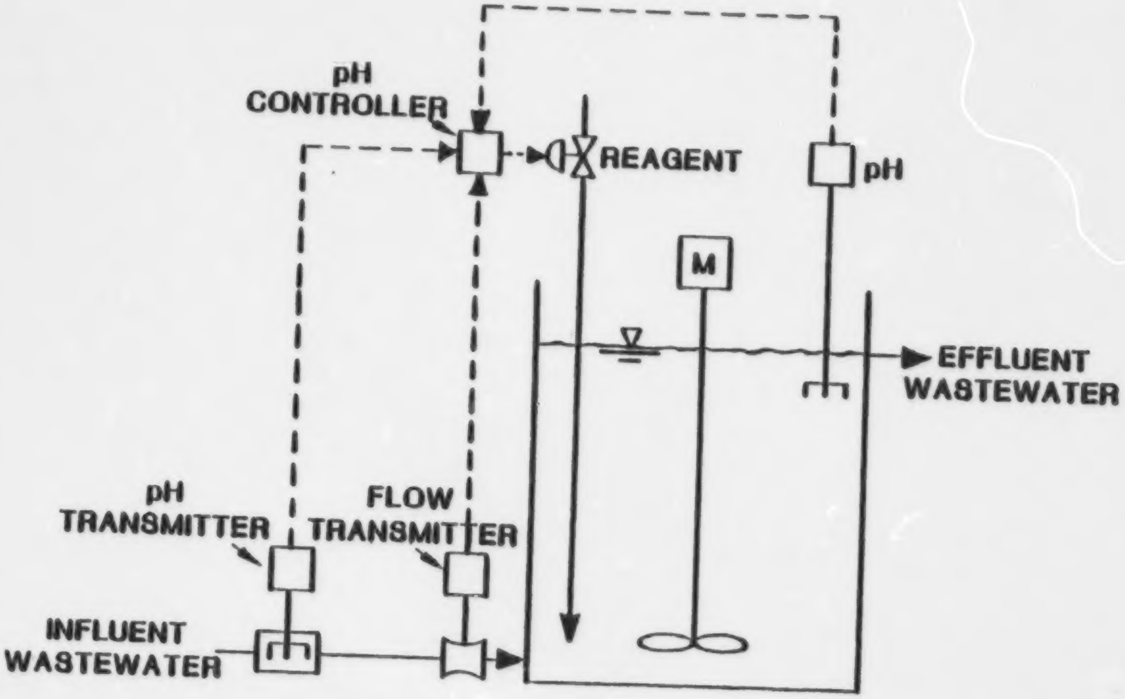
pH
CONTROLLER
REAGENT
pH
M
EFFLUENT
WASTEWATER
pH
TRANSMITTER
FLOW
TRANSMITTER
INFLUENT
WASTEWATER

Figure 14. Feedback-feedforward mode of pH control.

systems; namely, the controller is continuously approaching the desired pH but does not reach it before some of the wastewater flows through the reactor. The reactor pH is always different from the desired pH. This fact means that the set point pH will have to be offset to compensate for this difference. The offset will vary with chemical demand and should be set based on average wastewater conditions. The offset can only be set by trial and error. This system is very suitable for batch operations which do not experience the offset problem and for continuous flow systems with a relatively consistent wastewater which will allow establishment of an effective offset.

Integral Controllers

Integral control signal generators (reset controllers) are used in conjunction with proportional controllers to eliminate the offset problem. This is accomplished by generating a control signal that is proportional to the time since the pH was last at the set point. This signal is added to the proportional error signal. As the proportional signal drifts away from the set point for the reasons described in the previous discussion, the integrator generates a progressively larger control signal until the pH is forced back to the set point. Once the set point is reached, the integral signal drops back to zero and the whole process begins again. This type of controller is useful when close pH control is required and where the waste flow is not consistent either in volume or buffering capacities. Integral control is never used in conjunction with batch operations.

Derivative Controllers

Derivative control signal generators are used primarily when the pH must pass through a region of low buffer intensity as indicated in a titration curve by a line segment with a very large slope. The derivative controller generates a signal proportional to the rate of change of pH with respect to time. As an example, if the pH is constant the proportional signal is zero. If the pH is rapidly diverging from the set point, a large control signal is generated to correct the pH. If the pH is rapidly approaching the set point, a large negative control signal is generated to slow the approach to the set point. Once generated, the derivative signal is added to the error signal and the integral signal (if present).

The derivative control technique is often used in conjunction with proportional control for batch neutralization when the set point is in a poorly buffered location on the titration curve. It is also used in conjunction with proportional and integral control (a PID device) for continuous flow systems when the pH must pass through a poorly buffered range on the titration curve. Care must be exercised when using derivative control for continuous systems. If the derivative control is made too sensitive, the system may oscillate between high and low pH because of the lag or dead time in the system.

Programmable Controllers

Programmable controllers are sophisticated controllers that generate control signals based on a logic sequence that is programmed into the controller. For example, the controller can check the reactor pH and choose an appropriate proportional gain depending upon whether the system is operating in a high or low buffer region. Similarly, an integral and proportional response rate could be selected also. There is virtually no limit to the complexity and diversity of control strategies that can be built into these systems. Therefore, it is necessary that the process design manual and manufacturer's literature be referenced to understand individual programmable controllers.

OPERATIONAL PROCEDURES

The operational objective of pH adjustment is to control the addition of acidic and basic chemicals to the wastewater such that a desired pH can be achieved and maintained in the wastewater. This objective should be accomplished with the use of minimal amounts of chemicals in an effort to keep costs down and effluent total dissolved solids from becoming too high. The latter is especially true when several pH adjustment steps are performed on the wastewater prior to discharge.

Process Monitoring

Process monitoring of the pH adjustment process should consist of continuously monitoring and recording effluent pH from the pH control process. This information is essential to assure that the pH is being maintained within the critical limits required for metal precipitation, cyanide oxidation, chromium reduction, or other pH-sensitive treatment processes. Flow and influent pH must also be measured on a continuous basis for feedforward control, and as frequently as practical for feedback control where such information can be used to understand deviations in the effluent pH. Additionally, reactor temperature should be measured periodically or when poor pH adjustment occurs. Temperature can change the speed at which pH adjustment chemicals react and can affect the calibration of pH monitoring equipment. All pH probes should be calibrated daily with fresh buffer solutions and flow meters monthly. Calibration of pH meters involves the use of standards of at least two pH values; standards of pH 4.0, 7.0, and 10.0 are recommended.

In addition to the standard tests just described, titration curves should be prepared for the influent wastewater for each pH adjustment process. These curves should be prepared from both composite and grab samples using the same chemicals that will be used in the actual pH adjustment. The frequency for preparing these curves will vary greatly from one pH adjustment process to another depending primarily on the variability of the waste. As a minimum, a sufficient number of titration curves should be prepared to define the normal characteristics of the wastewater and then at least on a quarterly basis to assure that the wastewater is not gradually changing its characteristics. Whenever poor pH adjustment or process changes occur, new titration curves should be prepared and compared to the historical titration curves. If the curves differ significantly, the upset was probably caused by the non-characteristic waste. If the change represents a permanent change in the characteristics of the wastewater, the pH controllers will probably need readjustment.

Process Control Strategies

The four primary operating variables which enable the operator to control the pH adjustment process are pH controller adjustments, treatment chemicals, equalization, and mixing.

pH Controller Adjustments--

As previously discussed, pH controllers use a variety of control strategies to generate control signals. The common adjustments that can be made to the controllers will be described below. The applicable manufacturer's literature and any available design manuals should be referenced for specific systems when available. This is particularly important when manufacturers use terminology different from that used in this manual. It should be stated also that the adjustment procedures presented here are simplified. Whenever possible, fully-trained control and instrumentation personnel should be used to perform comprehensive adjustment procedures.

On-Off Control--On-off control has two primary adjustments; they are the set points for turning chemical feed equipment on and off. These set points should bracket the desired pH such that when the pH starts to move away from the desired pH the chemical feed pumps are turned on. Then, when the pH passes the desired pH in the reverse direction, they are turned off. The set points, of course, have to be selected such that the pH is maintained within acceptable limits. They also must be adjusted such that the set point for turning the equipment off is not too close to the set point for turning the equipment on. If the two set points are too close, the equipment will cycle on and off at an excessive rate. This can cause mechanical equipment to wear and sometimes can cause electrical equipment to overheat. The set point for turning on the equipment is usually controlled by adjusting the "set point" setting while the set point for turning off the equipment is controlled by the "dead band" setting. The "dead band" setting can be preset by the manufacturer (internal) or can be field adjusted (external).

Proportional Control--The primary control adjustments on a proportional controller are the set point and the gain adjustment. The gain adjustment determines the magnitude of the control signal relative to the pH error (actual minus set point pH). That is, as the gain is increased the magnitude of the control signal relative to the error is increased. The gain should typically be set as high as possible without sending the system into oscillation. Oscillation can occur when the gain is too high and either flow, pH, or buffering capacity of the wastestream changes. The controller detects the change and responds with a corrective signal. The effects of the corrective signal are not sensed by the controller, however, for a period equivalent to the system dead time. Hence, the system can over-respond when the gain is too high and can cause the pH to pass the set point in the other direction. This condition is not in itself bad, unless the pH enters an unacceptable range or continues oscillating for an extended period of time. If either condition occurs, the gain should be decreased. If natural oscillations are not present at the time of adjustment, they can be generated by adding directly a small quantity of base to a pH reduction unit or acid to a unit designed to increase pH. The acid or base should be added such that it does not cause more than a 1 or 2 pH unit change in the process effluent. It should be noted that some manufacturers use a "proportional band" control instead of a gain control. This control functions identically to a gain control except in reverse. Increasing the proportional band decreases the gain.

The set point for proportional only controllers may have to be set at a pH value slightly different from the desired pH value. This is for the reason discussed under "Description of Equipment". The offset will be strictly a matter of trial and error. Typically as the gain is increased the offset can be decreased. Likewise, as buffering intensity increases the offset must be increased. In highly variable flow systems, there may be no need for an offset because of the frequent swings in pH which will negate the advantage of an offset.

Proportional Plus Integral Control (PI Control)--The function of the integral mode is to eliminate the need for proportional offset. If too much integral action is used, the result will be an oscillation of the measurement as the controller drives the valve from one extreme to the other. If too little integral action is used, the measurement will return to the set point too slowly. The integral action adjustment controls how rapidly the integral control signal changes as a function of time. Among the various controllers manufactured, the integral action adjustment is calibrated in one of two ways--either in minutes per repeat, or the number of repeats per minute. For controllers measuring integral action in minutes per repeat, the smaller the integral number, the greater the action of the integral mode. On controllers that measure integral action in repeats per minute, the adjustment indicates how many repeats of the proportional action are generated by the integral mode in one minute. Thus, for these controllers, the higher the integral number, the greater the integral action. The proper amount of integral action depends upon the system dead time. The longer the system dead time, the less the integral action must be.

A simple way of adjusting the integral action is to set it to its minimum action position and adjust the proportional gain to its optimum position as described in the previous section. Then the system is allowed to come to steady state. Achievement of steady state may require some waiting if proper equalization is not practiced upstream and the system continuously fluctuates about the set point. When steady state is reached, a very slow pattern of pH gradually increasing to the set point and then moving away in the same direction should be evident. The integral action adjustment should then be increased gradually. The pattern should occur at an increasing rate with the pH deviations from the set point becoming less and less. If too much integral action is applied, the pH will start fluctuating significantly to both sides of the set point. It must be remembered when performing the adjustment that if the integral adjustment is in minutes per repeat, the integral action increases with decreased settings on the adjustment. Conversely, for adjustments marked in repeats per minute, the larger the setting, the larger the integral action.

The above procedure is usually satisfactory for field adjustments when the manufacturer's recommended procedures are not available or when qualified instrumentation and control personnel are not present. When the manufacturer's procedures or qualified personnel are available, they should be utilized.

Proportional-Integral-Derivative (PID Control)--The derivative mode opposes the rapid changes in pH that often occur when the pH adjustment procedure enters a poorly buffered section of a titration curve. The derivative response adjustment is measured typically in minutes. The higher the reading on the adjustment control, the more derivative action present. Too much derivative action causes excessive response of the controller and cycling in the measurement. Too little derivative action has no significant effect. As with the integral control, the system dead time is fundamental with respect to the maximum allowable derivative response. If the derivative response exceeds the system dead time, the system will become unstable and will oscillate.

A field method for adjusting the gain when manufacturer's recommended procedures or qualified instrumentation personnel are not available is provided below:

1. Set the integral to maximum time (minimum integral action).
2. Set the derivative to minimum time (minimum derivative action).
3. Adjust the gain to an optimum setting as before, except that a slight cycle should remain in the measurement.
4. Increase the derivative time until the cycle stops.
5. Increase the gain until the cycle starts again.
6. Repeat Steps 4 and 5 until further increases in the derivative time fail to stop the cycle.
7. Decrease the gain to stop the cycle.

8. Set the integral time equal to derivative time. **NOTE:** If the integral time is expressed as beats per minute, the time integral control should be set to (1/derivative setting).

pH Adjustment Chemicals--

The operator often has some control over the chemicals used for pH adjustment. Factors which should be considered in selecting a suitable chemical for a wastewater pH adjustment process include speed of reaction, buffering qualities, product solubility, reagent cost, and availability. A discussion of some common neutralizing agents follows.

Lime Materials--Lime is a term used to designate calcined or burned limestone (quicklime or CaO) and its hydrated derivative [hydrated lime or $Ca(OH)_2$]. The two basic types of limestone used are high calcium and dolomitic. High calcium limestones consist chiefly of calcium carbonate with a small amount of magnesium carbonate. Dolomitic limestones contain nearly equal molar quantities of calcium and magnesium carbonate. Typical impurities present in the limestone in amounts of less than five percent include silica, iron, and alumina.

The reactivity of limestones differs with physical characteristics (e.g., size and shape) and chemical composition. As a rule, high calcium limestones are more reactive than dolomitic limestones; however, pronnounced physical characteristics may produce exceptions to the rule. Theoretically, dolomitic limestone has greater basicity, but actual or available basicity depends upon the conditions of application. Pulverized limestone is a stable noncorrosive product that is amenable to dry feeding. It is available in bulk or in 36-kg (80-lb) bags. Various mechanical conveyors are suitable for unloading the bulk material.

Quicklime - Quicklime has an affinity for carbon dioxide and water. Under normal handling or storage conditions, quicklime will air-slake, that is, absorb moisture and carbon dioxide from the atmosphere, causing physical swelling and a marked loss of chemical activity. Consequently, quicklime must be stored in moisture-proof areas that are free from carbon dioxide. Because of this potential loss of effectiveness, quicklime is usually consumed within a few weeks after manufacture.

Quicklime is available in various forms, ranging from 20-cm (8-in) lumps to pulverized, and is supplied in bulk or in 36-kg (80-lb) bags. Dust from pulverized quicklime can irritate eyes and skin. Although it can be fed dry, for optimal efficiency it is slaked (hydrated) and slurried before use under conditions that will yield maximal reactivity. Improper slaking will adversely affect reactivity. Slaking usually is carried out at temperatures of 82° to 99° C (180° to 210°F). The slaking reaction may reach completion in 10 minutes with highly reactive limes or in more than 30 minutes for limes of lower reactivity.

Following slaking, the lime putty usually is slurried with water to a concentration of 10 to 35 percent (based on dry solids) for feeding purposes. Because the slurry is subject to deterioration from carbonation during storage, it is customary to use it soon after it is made.

The applicability of lime to specific situations may be expected to vary significantly from supplier to supplier. Testing under actual or simulated process conditions is the only sound basis for determination of relative applicability; empirical basicity tests normally are of value only when the application is analagous to the test.

Hydrated Lime--Hydrated lime is suitable for dry feeding or for slurrying. Dust from hydrated lime, a fine powder, can cause eye and skin irritation. The storage characteristics of dry hydrated lime are superior to quicklime, but, as with any strong alkali, carbonation can cause deterioration. Hydrated lime is supplied in bulk or in 23-kg (50-lb) bags. Bulk unloading is usually accomplished by pneumatic conveyor.

Sodium Hydroxide--Sodium hydroxide (caustic soda) is a highly reactive alkali that is marketed in solid or solution form. The solution form is the most convenient for handling because burn hazards to personnel are minimized. The solid form is hygroscopic, and both the solid and the solution are subject to deterioration from carbonation during prolonged storage. Solid and liquid sodium hydroxide are supplied in drums, but only the liquid form is available in bulk (tank car or truck). Heated tanks should be used for storage of 50-percent solution in situations where the ambient temperature is likely to fall below 12°C (54°F).

Sulfuric Acid--Sulfuric acid is a highly reactive acid that is supplied in liquid form, usually in concentrations of 98 percent. The concentrated acid is strongly hygroscopic and presents a burn hazard to personnel. Dilute solutions are highly corrosive to iron and steel, whereas concentrated solutions (>93 percent) are not corrosive to iron and steel. A maximum freezing point of 8°C (46°F) is exhibited at a concentration of 85 percent. Depending on the concentration, freezing protection may be required during storage and transport. Sulfuric acid is shipped in carboys, barrels, tank cars, or trucks.

Equalization--

Equalization is essential to successful pH adjustment particularly when the set point pH is in a poorly buffered region of the titration curve. The importance of equalization can best be understood by examining the "dead" time concept. If the pH, flow, or buffer capacity of the wastewater stream changes significantly in a time frame shorter than the dead time of the control system, proper pH control cannot be achieved. Similarly, as the rate of change approaches the dead time pH control becomes more difficult and more sophisticated controllers that incorporate integral and derivative action are required.

Whenever poor pH control occurs, the operator should conduct a monitoring program immediately to determine the variability of the influent to the pH adjustment step and to determine if the poor performance coincides with the variability in the influent. If it does, the operator should troubleshoot the equalization process. As a general rule, increased equalization makes pH control easier.

Mixing--

Adequate mixing is essential for good pH adjustment for three closely related reasons. First, mixing is required to blend pH adjustment chemicals with the wastewater. Second, mixing decreases reactor dead time by dispersing the chemicals rapidly throughout the reactor. Lastly, it provides equalization and homogeneity throughout the reactor. The latter is important because the feedback pH control probe will respond to the non-homogeneous contents of the reactor just as readily as to fluctuations in the influent characteristics.

To acheive good mixing, the minimum horsepower requirements presented in Table 5 should be provided for mixing. The influent and effluent devices should also be located at opposite sides of the reaction tank, ideally with one at the top of the tank and one at the bottom. If circular tanks are used, side wall mixing baffles must be provided. The tank must also be checked periodically for solids deposition in the bottom of the tank which can adversely affect mixing and decrease the hydraulic residence time of the system. Similarly, the mixer impeller should be checked for wear or breakage.

Proper location of the chemical feed and the feedback pH probe is also essential and should be verified by the operator. The chemicals either should be added directly at the point of inflow to the system or directly into the mixing vortex. Care should be exercised in the latter case to assure that the chemicals will not corrode the impeller or impeller shaft. The pH probe for feedback control should be located in the outflow of the reactor just outside the reactor. This provides the most representative sample for process control.

Influent and pH-adjusting reagent should enter at the same point, premixed for best results. The direction of inflow should oppose the direction of agitation for most effective backmixing.(16)

The exit should be diametrically opposite to the point of entry, to minimize short-circuiting. Otherwise a significant part of the influent could pass by the vessel without treatment, and uncontrollable variations in effluent quality could result. If the influent enters at the bottom on one side, effluent should leave at the top from the other side, and vice versa.(16)

In neutralization of industrial wastes, many streams with widely differing properties are usually combined for treatment in a single vessel. Often both acid and basic reagents are required when the influent pH may be on either side of 7. In these instances, reagent can be saved by providing a retention vessel upstream of the neutralization tank. This smoothing vessel should have enough residence time to accommodate the largest expected transient influent variations.(16)

Properly locating the point of measurement is as important as locating the vessel exit, and is, in fact, tied to it. A representative measurement of effluent quality is essential and so electrodes should be placed in the effluent stream. However, they should not be placed out of the mixed zone. Dynamic response is also important, so every effort should be made to maintain a reasonable flow past the electrodes. One tries to avoid the use of stilling wells or other protective devices which restrict flow, and to avoid locations where flow is variable.(16)

Submersible electrode assemblies will always be more responsive than flow-through assemblies since they are directly inserted within the process stream. Flow-through assemblies were designed for pressurized service with a sample withdrawn continuously for measurement. Although desirable for easy maintenance, the additional delay caused by the sample line impedes control action.(16)

Submersible electrodes are used primarily in open vessels. They should extend only slightly below the surface of the liquid to minimize the possibility of leakage. Occasionally, however, deeper submergence is necessary. The assemblies may be air-purged to protect against leakage even under severe conditions.(16)

Flow-through electrode assemblies are required for pressurized service, or whenever a sample must be treated prior to measurement. Sample lines should be as short as practical and velocity high to minimize dead time. High velocity also helps keep the electrodes clean, although excessive velocity can cause erosion and even cleavage of the electrodes. A velocity of 2 ft/sec past the electrodes is probably as high as tolerable for long life.(16)

TYPICAL PERFORMANCE VALUES

With adequate equalization, the proper selection of control strategies, and the proper adjustment of all control equipment, the wastewater exiting a pH adjustment step should be controllable within ± 0.25 pH units.

TROUBLESHOOTING GUIDE

A guide for troubleshooting the pH adjustment process is presented in Table 9. The pH parameter is one of the first indicators of potential treatment plant upset conditions. Problem areas include, in addition to shock loads, pH instability related to controller settings or breakdown, chemical feed and mixing equipment failure, and chemical system used.

TABLE 9
pH ADJUSTMENT TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Oscillating or unstable pH. Previous performance satisfactory.			
1a. Shock loading of flow or pH.	- Check influent flow and pH for abnormal levels or fluctuations.	- pH controllers are optimized for specific flow, pH, and buffer intensity conditions. Changes in these parameters can cause controller instability.	- Prevent influent pH and flow in variations either through increased equalization or changes in operating procedures. Tune controller to make it less sensitive to fluctuations.
1b. Buffer intensity of wastewater changed.	- Prepare new titration curve and compare to previous curves. Check to see if chemical feed system at maximum capacity.	- Decreases in buffer intensity can cause controllers to oscillate. Large increases in buffer intensity may cause chemical demand to exceed the chemical feed system capacity.	- Increase equalization; readjust controller to reflect new conditions; modify chemical addition equipment if its capacity is exceeded. If buffer intensity decreased, consider using chemical that provides buffering such as soda ash.
1c. pH probe failure.	- Check condition of probe and all electrical connections. Clean and calibrate probe. Check condition of electrolyte fluid in probe if probe uses it.	- Dirty probes respond slowly and irregularly. Routine maintenance of probes is essential.	- Clean, calibrate, repair, and adjust as required.
1d. Poor mixing.	- Check mixer, mixer impeller, all baffles, and the tank for solids deposition.	- Poor mixing can cause short circuiting and poor chemical dispersion.	- Repair as required. Clean tank.
1e. Chemical feed equipment failure.	- Check feed equipment for smooth operation, leaks, and any blockage in the chemical delivery path. Check calibration of all chemical metering systems.	- If the pH adjustment chemical is not properly delivered to the reactor, no pH adjustment can occur.	- Repair and adjust as required.

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TABLE 9
(Continued)
pH ADJUSTMENT TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
1f. Defective chemicals.	- Check chemical feed containers for chemical content, chemical strength, and formation of solid lumps when dry chemicals are used.	- Improper or defective chemicals can adversely affect pH adjustment. Improper chemical concentration can be placed in feed tanks by accident or ignorance.	- Replace defective chemicals.
1g. Controller breakdown.	- Check all other possible causes.	- Controllers can break down, especially from lightning or other electrical surges.	- Call qualified repairman.
OPERATING PROBLEMS 2: Slow controller response.			
2a. Improper setting on proportional gain control.	- Check gain setting and date of last adjustment.	- Low gain will cause sluggish response.	- Adjust controller proportional gain.
2b. Dirty pH probe.	- Check condition of probe.	- Dirty probes will respond slowly, particularly if oily material present in wastewater.	- Clean probe.
2c. Excessive "dead" time.	- Check mixing; check feedback probe location and type.	- Increasing mixing will decrease dead time. Probe should be located in reactor outflow just outside of reactor. Probes that insert directly into outflow are quickest.	- Increase mixing; move probe; use probe that is inserted directly into outflow.
2d. Slow reacting chemical.	- Check type and form of chemicals. Lime reacts slowly.	- Liquids react faster than solids or slurries.	- Change chemicals.
OPERATING PROBLEM 3: pH offset.			
3a. Controller is proportional only and the pH set point has not been offset.	- Check type and set point of controller.	- Proportional only controllers require that the set point pH be slightly offset from desired pH.	- Adjust by trial and error.

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TABLE 9
(Continued)
pH ADJUSTMENT TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
3b. Controller is proportional-integral type and integral action setting is too low.	- Check type and integral control setting.	- Integral control does away with the offset requirement of proportional controllers if adjusted properly.	- Adjust as required.
3c. Chemical feed system inadequate.	- Check chemical feed system for proper operation and delivery rate.	- Chemical feed system may be unable to deliver chemicals at a sufficient rate to adjust pH.	- Modify feed system; use more concentrated chemicals; decrease wastewater flow.
OPERATING PROBLEM 4: pH oscillates around set point.			
4a. Improper controller adjustment.	- Check type controller and date of last adjustment.	- Improper adjustment of proportional, integral, or derivative control can cause oscillation.	- Adjust as required.
4b. System "dead" time too long.	- Check mixing, type of chemicals used, and location of feedback control.	- Excessive dead time limits a controller's ability to respond to pH changes. If rapid changes occur, the system will oscillate about set point.	- Improve mixing; use liquid chemicals that react quicker; place pH probe directly in outflow just outside of tank. Use proportional-integral-derivative controller; use chemicals with inherent buffering capacty such as soda ash.

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SECTION 9

METAL PRECIPITATION

INTRODUCTION

Precipitation is a treatment technique which is commonly used to remove the following metals from wastewater: cadmium, trivalent chromium, copper, lead, nickel, and zinc. Precipitation is the process of adjusting the pH of a wastewater to the minimum solubility of the metal or metals. The insoluble metal precipitate which is formed can then be easily removed from the wastewater by sedimentation and/or filtration. Soluble metals are very stable in solution and will not settle out even at long detention times.

THEORY OF OPERATION

Precipitation of metals from solution involves adjusting the pH to the point of minimum solubility. An example of the solubility of a metal (lead) versus the pH of the wastewater is presented by the curve in Figure 15. The optimum treatment for a wastewater with characteristics shown in Figure 15 would be to adjust the pH of the wastewater to 9.0 and then separate the insoluble precipitate from solution by clarification or filtration. Removing 100 percent of the insoluble precipitate or floc would result in an effluent lead concentration of 0.20 mg/L. If the pH of the wastewater were adjusted to 7.5, then the effluent lead concentration would be 0.8 mg/L for 100 percent removal of the insoluble precipitate.

Heavy metals can exist in either the particulate form or the soluble or dissolved form. The particulate metal concentration represents

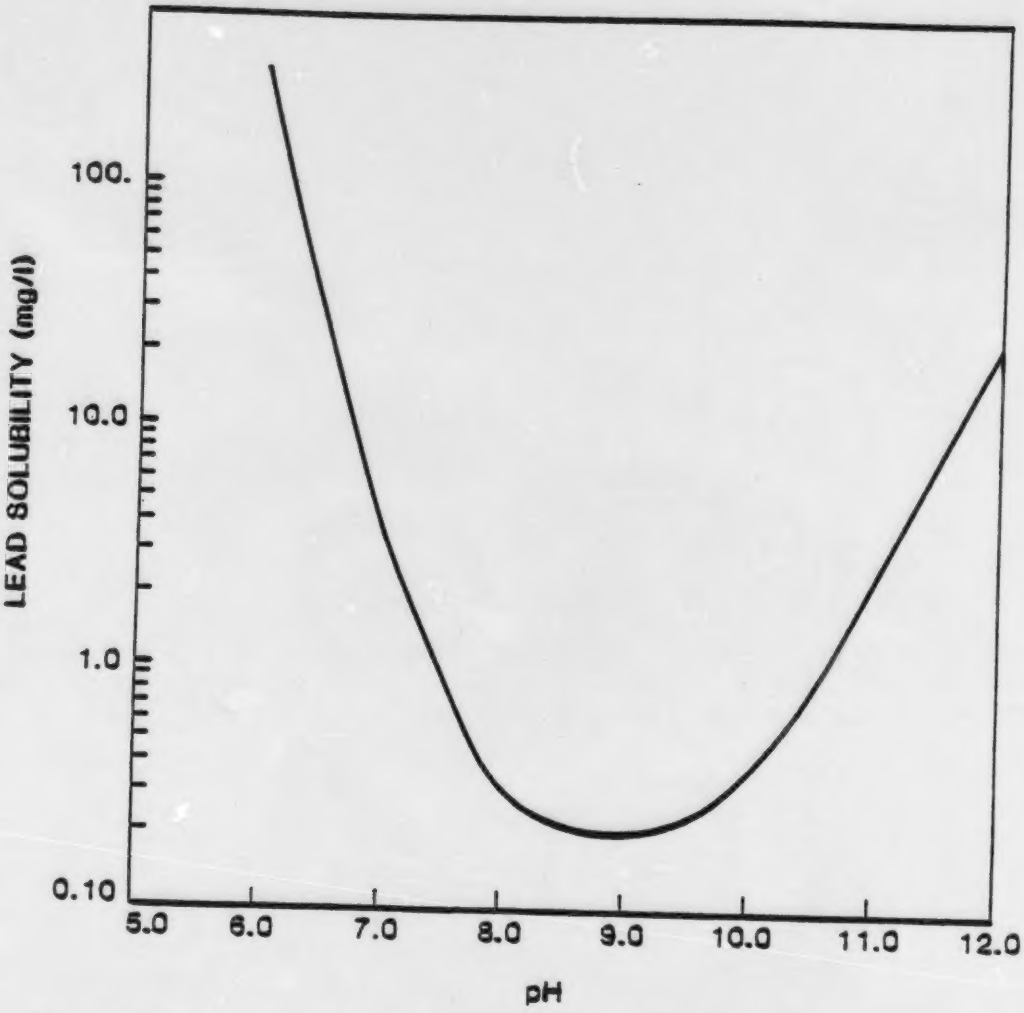

Figure 15. **Lead solubility for a typical wastewater.**

the difference between the total metal concentration and the soluble metal concentration. At each pH value, the soluble metal concentration can be determined theoretically from pH solubility diagrams or experimentally by analyzing for the dissolved metal concentration. The dissolved metal concentration of a solution can be measured by filtering the sample with a 0.45 micron filter and then analyzing the filtrate for the metal concentration. Analyses of aqueous solutions for metal concentration is performed using an atomic absorption spectrophotometer (AAS), an instrument which measures the radiant energy absorbed as the sample passes through a flame. Procedures for the analysis of most common metals by AAS are contained in reference 8.

The soluble metal concentration of a sample should not be based on theoretical considerations because of the effect that other ions have on the solubility of a metal. An example of the effect that carbonate has on lead solubility can be observed in Figure 16. This figure shows that the lead solubility at a pH of 9.0 for carbonate concentrations of 16, 50, and 10,000 mg/L as $CaCO_3$ is 0.07, 0.35 and 2.5 mg/L, respectively. Other metals can be similarly affected by ions in solution. Because of this effect, the optimum pH value should be based on test data rather than theoretical values.

DESCRIPTION OF EQUIPMENT

The processes generally used in metal precipitation include pH adjustment, sedimentation, and sometimes filtration. The functions of pH adjustment and sedimentation processes must not be confused. The pH adjustment step simply converts a metal from the soluble (ionic) form to the insoluble (hydroxide precipitated) form. However, the total concentration of the metal in the wastestream does not change during this process. The sedimentation process removes particulate metal from the wastestream. However, the sedimentation process does not decrease the soluble metal concentration.

The relationship between soluble and total metal concentration and the treatment processes involved is presented in Figure 17. Reading

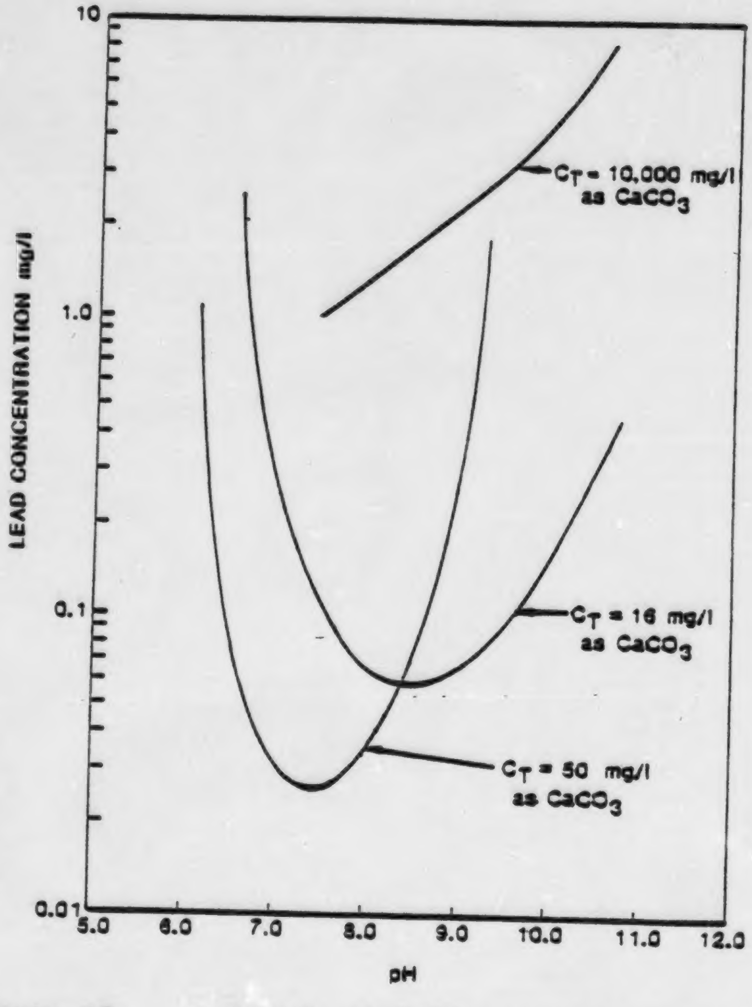

Figure 16. **Lead solubility as a function of carbonate concentration.** (C_T)

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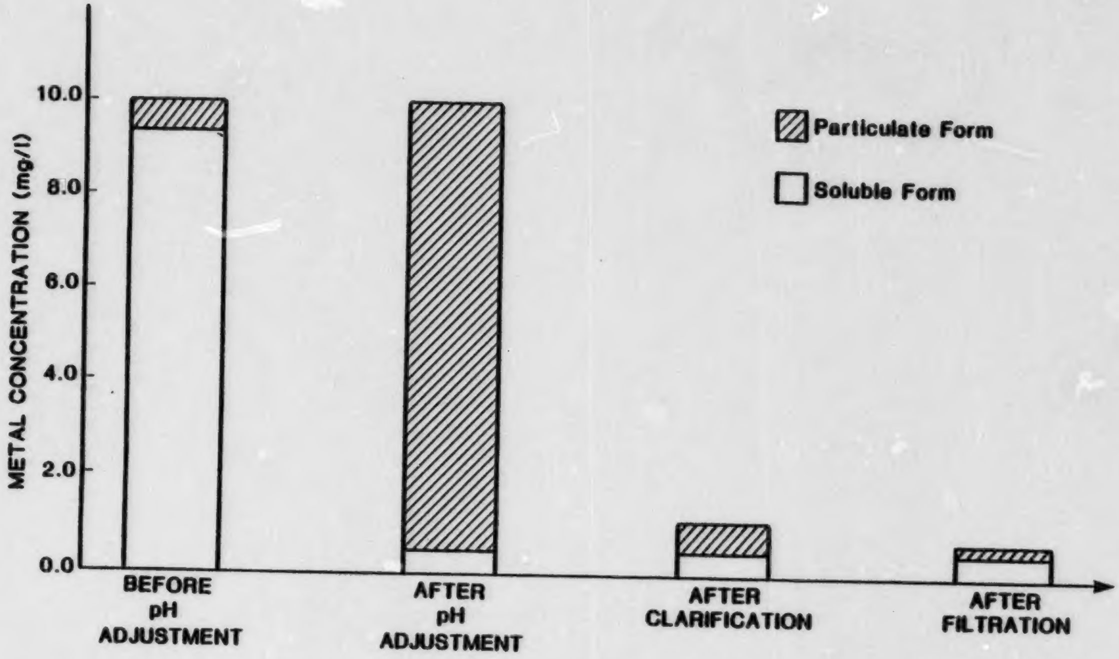


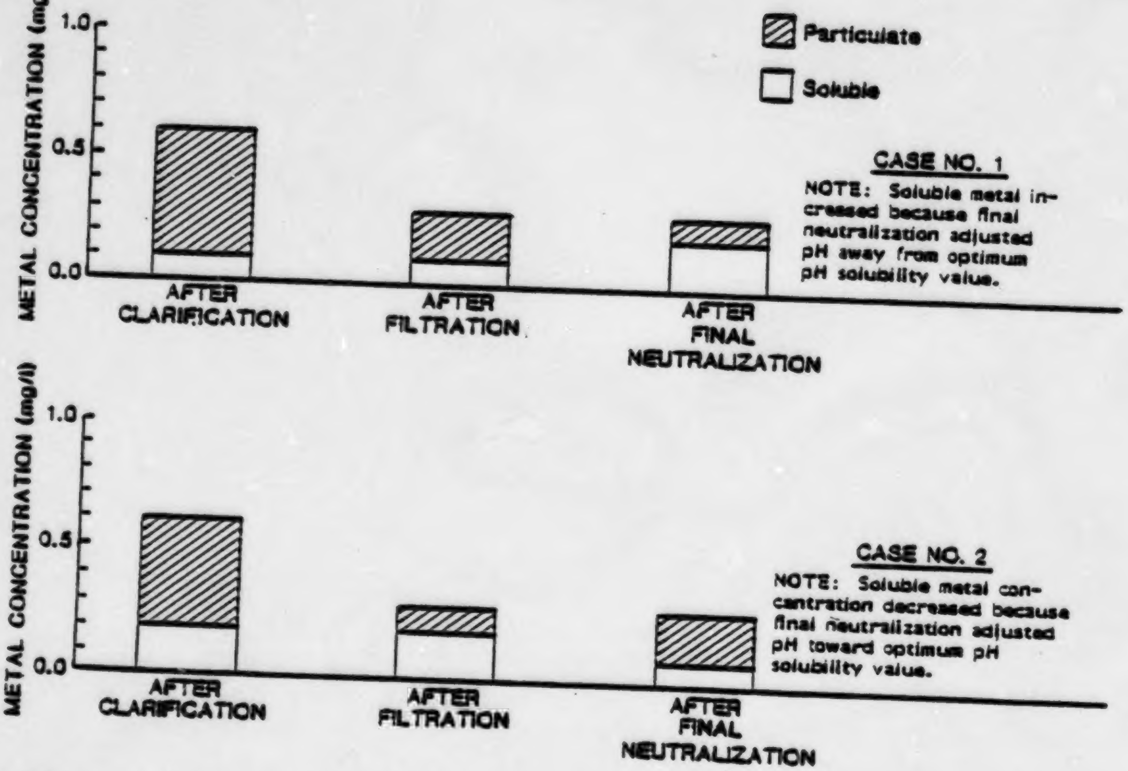
Figure 17. **Metal concentration versus treatment process.**

from left to right on Figure 17, it can be seen that the pH adjustment step changes the relative proportions of soluble and insoluble metal content, but does not in itself reduce the total metal concentration. However, clarification in general removes the majority of the particulate matter, and filtration removes even more, while leaving the soluble metal concentration unchanged. Because the optimum pH value for precipitation of a metal may occur at a pH greater than that allowed by regulatory authorities, post pH adjustment or final neutralization is sometimes necessary. The effect of final pH adjustment will be to change the concentration of the particulate and soluble metal concentration. Either form may increase or decrease depending upon the metal solubility, and the initial pH and final pH in the post pH adjustment process. However, the total concentration of the metal will not change during the process. The two possible effects that final neutralization can have on soluble and particulate metal concentration are shown in Figure 18. From Figure 18 as with Figure 17, it is apparent that changes in pH will change the concentration of the forms of the metal but will not increase or decrease the total metal concentration.

Changes in the pH of wastewater can occur as the result of acid or alkali addition such as in the final neutralization basin. However, changes in the pH of a wastewater can also occur because of introduction of CO_2 into the wastewater, especially for poorly buffered waters. Introduction of CO_2 into the water can occur slowly in a tank open to the atmosphere or more rapidly by aeration or turbulence.

OPERATIONAL PROCEDURES

The objective of precipitation is to cause the metal ion to form an insoluble precipitate which can be removed by separation techniques such as sedimentation or filtration. To control the metal precipitation process, the operator should perform the necessary process monitoring and should apply the necessary control strategies to the system variables.



NOTE: Soluble metal increased because final neutralization adjusted pH away from optimum pH solubility value.

NOTE: Soluble metal concentration decreased because final neutralization adjusted pH toward optimum pH solubility value.

Figure 18. **Metal concentration after treatment process.**

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Process Monitoring

Since precipitation involves a number of processes such as pH adjustment, sedimentation, and filtration, process monitoring will involve all these processes. The main parameters involved in monitoring each of the processes are total and dissolved metal, pH, and total suspended solids. The regular or continuous monitoring requirements are summarized in Table 10.

pH Adjustment --

The influent total metal concentration, effluent soluble metal concentration, and reactor pH should be monitored. Ions such as carbonates or phosphates may be analyzed to determine if these ions have an effect on metal solubility.

Sedimentation --

The effluent total and soluble metal concentration should be measured in order to determine the particulate metal concentration that is not removed by sedimentation. Influent and effluent suspended solids should be measured to determine the amount of sludge that must be removed. A correlation may exist between effluent suspended solids and effluent total metal concentration.

Filtration --

Since filtration is typically the last treatment process employed, effluent total metal concentration will indicate permit compliance. The influent and effluent particulate metal concentration should be determined to evaluate filter performance. Influent suspended solids should be measured to allow control of the filtration process.

The key to successfully operating a metal precipitation system is understanding the relationship between the particulate and soluble metal concentration and the treatment processes. An example of the difference between particulate and soluble metal concentration and how it affects permit compliance is shown in Figure 19. Case No. 1 presents data for a

TABLE 10
METALS PRECIPITATION
PROCESS MONITORING REQUIREMENTS

Process	Parameter	Frequency	Reason for Monitoring
1. pH Adjustment	Flow	Continuously	To adjust dosages for feedforward control.
	Influent Total Metal Concentration.	Daily	To determine mass loading.
	Effluent Soluble Metal Concentration.	Daily	To evaluate performance.
	Reactor pH	Continuously (Calibrate daily)	To adjust reagent dosages and for evaluating metal solubility.
2. Sedimentation or Filtration	Flow	Daily	To evaluate effect of hydraulic loading on metal precipitate removal.
	Influent TSS	Daily	To determine influent mass loading of TSS.
	Effluent TSS	Daily	To determine TSS removal performance and to establish correlation between metal concentration & TSS.
	Influent TSS-Effluent TSS (Mass Loadings)	Daily	To determine mass loading of sludge to be removed.
	Effluent Soluble and Total Metal Concentration	Daily	To determine particulate metal concentration in effluent and particulate metal removal performance of separation device.

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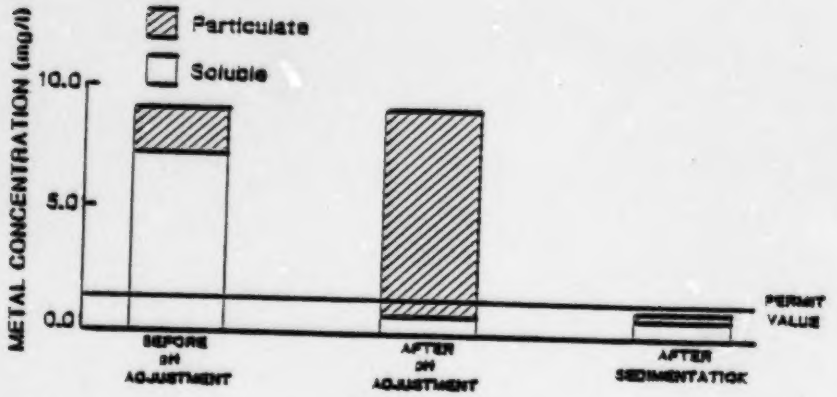
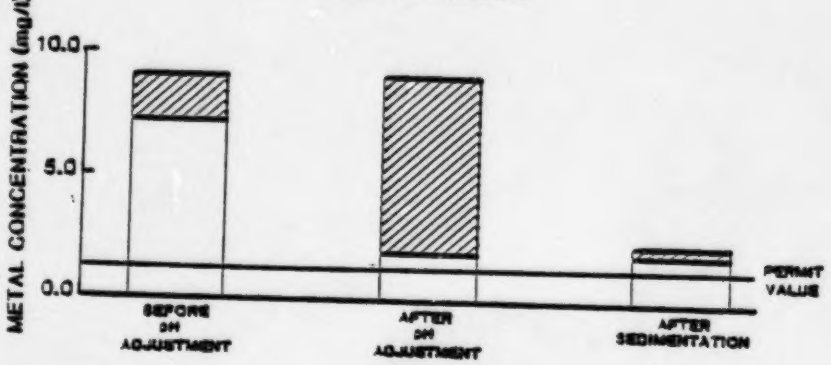
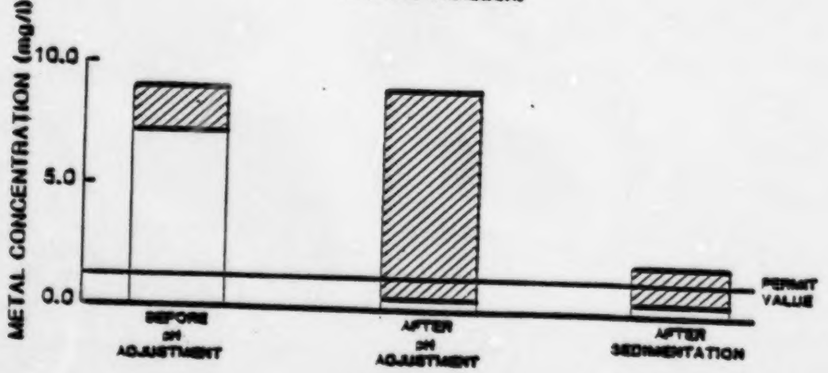


CASE NO.1
(Permit Compliance)



CASE NO.2
(Permit Violation)



CASE NO.3
(Permit Violation)

Figure 19. **Metal concentration versus treatment process.**

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treatment system which has good operation of pH adjustment and sedimentation. Case No. 2 presents a system which has poor operation of the pH adjustment process. This is evidenced by a high soluble metal concentration. Soluble metal can be measured by filtering a sample immediately after collection. Care must be taken that the pH does not change. A discussion of the variables which affect the solubility of each metal are presented in the PERFORMANCE portion of this Section.

The third case, Case No. 3, presents a treatment system which has good operation of the pH adjustment system but poor operation of the sedimentation process. Poor sedimentation performance will be indicated by high effluent suspended solids concentration and high particulate metal concentration. Particulate metal concentration is the difference between total and soluble metal concentration. The causes and remedies for troubleshooting the sedimentation process are presented in the section on sedimentation. The operator should not attempt to correct the sedimentation problem by installing a filtration unit because the unit will foul with solids. Most filtration systems should be installed for wastewaters that are low in suspended solids.

Process Control Strategies

The control strategies associated with operating a metal precipitation system involve the chemical reagent used in pH neutralization and the operating pH. Other operating variables associated with operating the unit processes (pH adjustment, flocculation, clarification, and filtration) are listed and discussed for each unit process.

Hydroxide Precipitation--

The most common anion used to precipitate metals from wastewater is hydroxide. Hydroxide is generally added to the wastewater as calcium hydroxide (lime) but sometimes added as sodium hydroxide (caustic). The primary advantage for using lime is that a good settling precipitate is usually formed. The advantage for using caustic is less sludge generation. The solubility of metal hydroxides is presented in Figure 20.

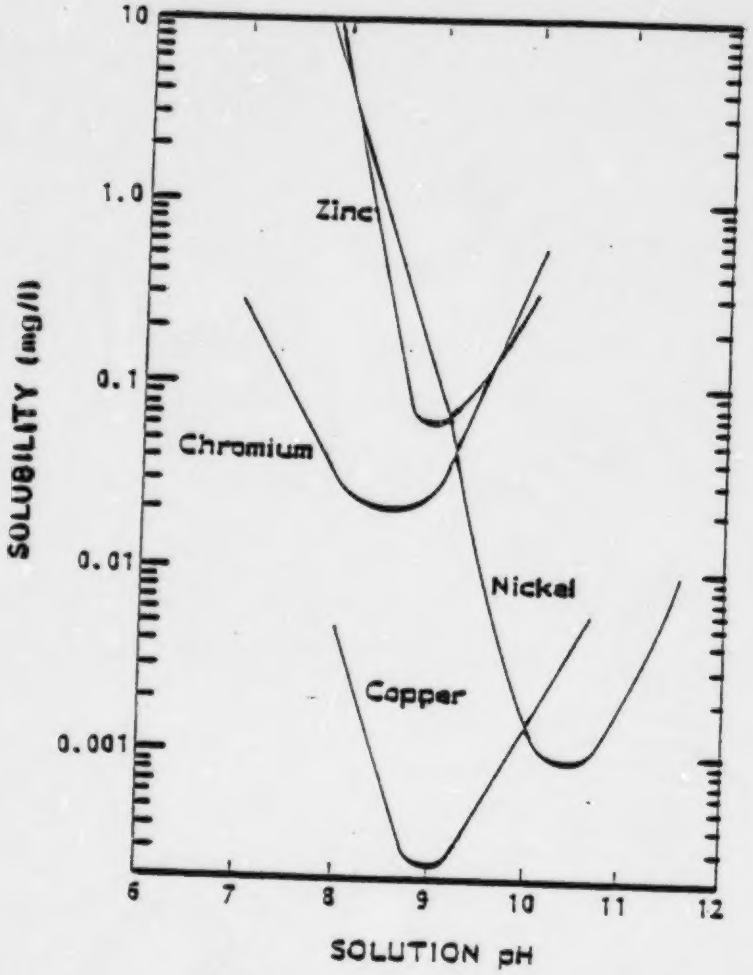

Figure 20. **Solubility of selected heavy metal hydroxides.**

SOURCE: USEPA, SULFIDE PRECIPITATION OF HEAVY METALS, EPA-600/2-80-139, JUNE, 1980, p. 104.

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Because of the different pH ranges for minimum solubility of various metals, staged precipitation is sometimes needed.

Staged precipitation is a series of two or three steps of a pH adjustment process with each step followed by a separation process such as sedimentation and/or filtration. An example of the necessity of staged precipitation is for a wastewater which requires removal of both nickel and trivalent chromium. The first stage would consist of pH adjustment to a pH of 8.5 followed by sedimentation and, possibly, filtration. The second stage would consist of pH adjustment of the wastewater from 8.5 to 10.5 followed by sedimentation and/or filtration.

Sulfide Precipitation--

Sulfide precipitation of heavy metals is gaining acceptance because most metal sulfides are even less soluble than metal hydroxides at alkaline pH values. Therefore, lower effluent metal concentrations can be accomplished through the use of sulfide rather than hydroxide. As with hydroxide precipitation, the solubilities of metal sulfides are pH dependent. The pH dependence for various metal hydroxides are presented in Figure 21. Figure 21 also shows the metal solubilities of metal sulfides. Sulfide can be added as hydrogen sulfide, sodium sulfide, or ferrous sulfide. If the sulfide is added as a water-soluble compound (e.g., H_2S or NaS), the process is referred to as soluble sulfide precipitation (SSP). If the sulfide is added as a slightly soluble salt (ferrous sulfide), the process is called insoluble sulfide precipitation (ISP). Figure 22 shows typical precipitation processes for hydroxide precipitation, SSP, and ISP.(4)

In addition to achieving extremely low solubilities for metal sulfides, the sulfide process has the ability to remove chromates and dichromates without preliminary reduction of the chromium to the trivalent state. Furthermore, the sulfide process will precipitate metals complexed with certain complexing agents. Iron sulfide has been demonstrated more effective for metal precipitation when chelating agents

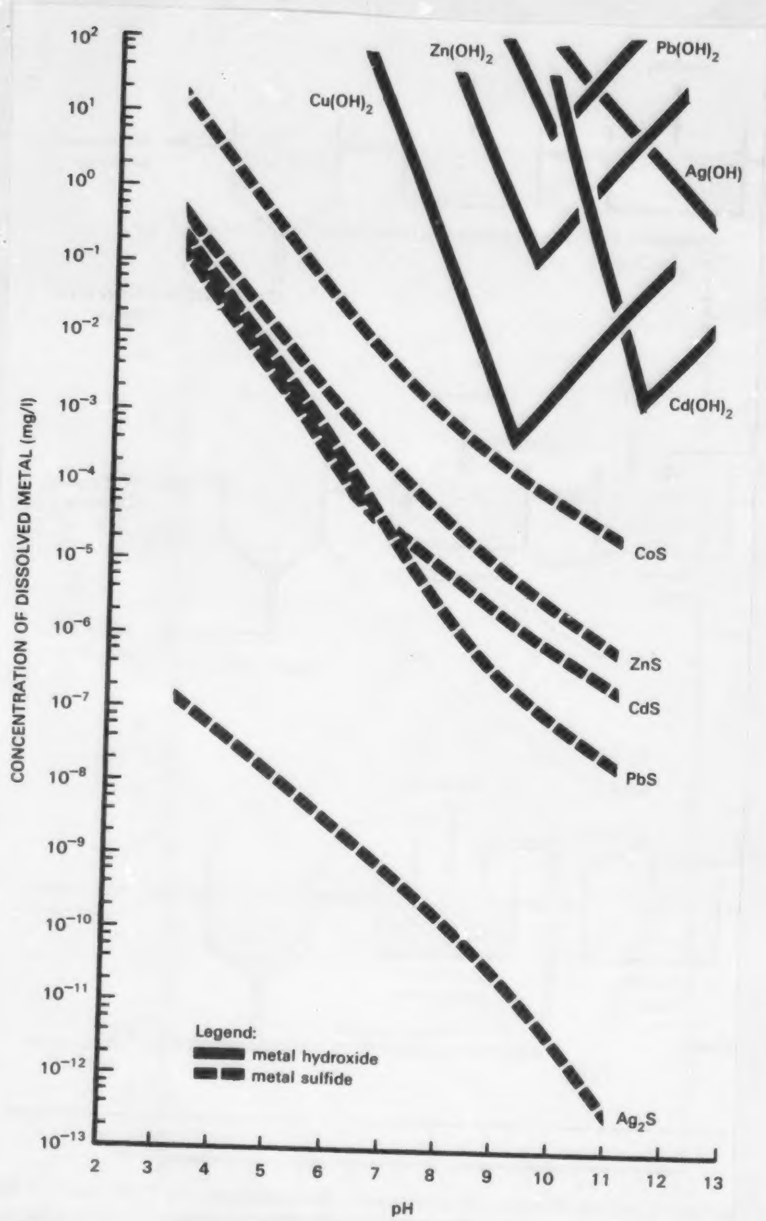

Figure 21. **Theoretical solubilities of metal hydroxides and sulfides versus pH.**

[illegible]

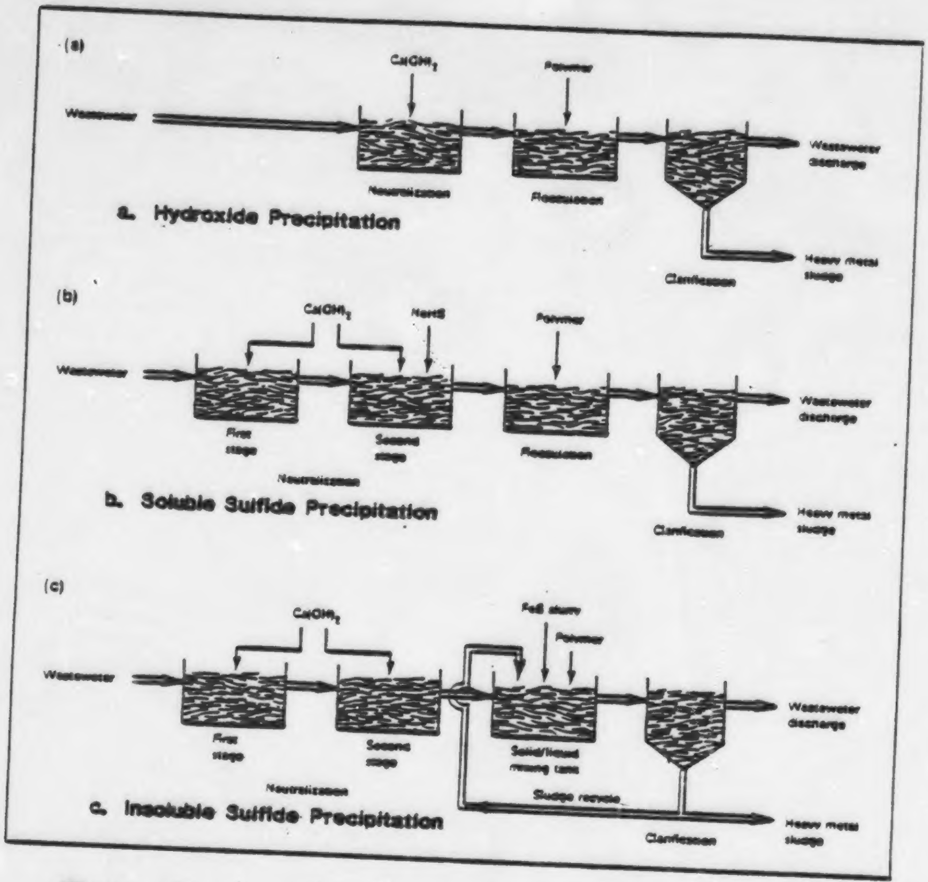
(a)
Ca(OH)$_2$
Polymer
Wastewater
Wastewater discharge
Neutralization
Flocculation
a. Hydroxide Precipitation
Heavy metal sludge
Clarification
(b)
Ca(OH)$_2$
NaHS
Polymer
Wastewater
Wastewater discharge
First stage
Second stage
Flocculation
Neutralization
b. Soluble Sulfide Precipitation
Heavy metal sludge
Clarification
(c)
Ca(OH)$_2$
FeS slurry
Polymer
Wastewater
Wastewater discharge
First stage
Second stage
Solid/liquid mixing tank
Neutralization
Sludge recycle
c. Insoluble Sulfide Precipitation
Heavy metal sludge
Clarification

Figure 22. **Wastewater treatment processes for removing heavy metals.**

SOURCE: EPA REPORT NO. EPA 625/8-80-003.

such as EDTA or Rochelle Salt are present.(17) These tests were performed for copper, cadmium, chromium (III), nickel, and zinc precipitation. One disadvantage of the sulfide process is the evolution of toxic hydrogen sulfide gas for certain sulfide reagents if the pH should decrease below 8.0. However, the usage of iron sulfide virtually eliminates the possibility of evolution of hydrogen sulfide. Another disadvantage of the process is that high levels of excess sulfide sometimes must be oxidized to sulfate before discharge.

A key to good operation of the sulfide precipitation is applying the correct amount of sulfide. As with any precipitation reaction, excess reactant (sulfide) must be present to drive the precipitation reaction to completion. However, because sulfide is toxic, sulfide addition must be carefully controlled with only a minimum of excess sulfide used. High levels of unreacted sulfide will require post-treatment such as aeration to oxidize sulfide to sulfate.

TYPICAL PERFORMANCE VALUES

Typical performance values for removal of metals commonly present in plating and finishing wastes are discussed in the following. Also discussed are the effects that various compunds or ions may have upon the shape of the pH-solubility curve.

Chromium

A pH range of 8 to 9 is recommended to achieve the minimum solubility of trivalent chromium. However, this range is very dependent upon the concentration of anions in solution, particularly carbonates and phosphates. Thomas and Theis(18) have demonstrated that a bicarbonate alkalinity and pyrophosphate at concentrations as low as 250 mg/L as $CaCO_3$ and 30 mg/L as P, respectively, together cause appreciable complexation and may make alternatives other than lime impractical. Thomas and Theis showed that if caustic was used for pH adjustment of a wastewater containing pyrophosphate and carbonates not only would the pH range of minimum solubility be altered, but the supernatant chromium concentrations would be greater than 1.0 mg/L. They recommended that lime should be substituted for caustic soda. The use of lime will cause precipitation and removal of most of the carbonate and pyrophosphate species from solution while providing doubly charged counter ions to aid in coagulation of the negatively charged $Cr(OH)_3$ colloid which exists at pH values above 8. An alternative to substitution of lime for caustic for solutions which contain chromium (III), carbonates, and pyrophosphates is to segregate the Cr(III) wastes from waste rinses which contain carbonates and phosphates. The advantage for this alternative is that the caustic sludge volume is much lower than the lime sludge volume.

Copper

The presence of anions can affect the solubility of copper. The pH range of minimum solubility for copper hydroxide without the presence of interferences is 7.5 to 11.0. The soluble copper concentration at this level is approximately 0.03 mg/L. However, the presence of carbonates can increase the soluble copper concentration.(19) Patterson showed that the soluble copper concentration for a solution with a carbonate species concentration of 500 mg/L as $CaCO_3$ was 4.5 mg/L at a pH of 7.5, 0.25 mg/L at a pH of 8.5, and 0.09 mg/L at a pH of 9.5. Therefore the presence of bicarbonate at a concentration of 500 mg/L as $CaCO_3$ will increase the copper solubility concentration 150-fold at a pH of 7.5

The operator can reduce the effect of carbonate by several methods. One solution is to reduce or eliminate the concentration of carbonates. An alternative is to use lime and operate at a pH of 10.0 or higher so as to form the insoluble calcium carbonate precipitate.

Lead

The pH range of minimum solubility for lead is 7.5 to 8.5 for lead hydroxide precipitation as seen in Figure 16. Patterson(20) noted that the effect of carbonate on lead solubility is a complex function of carbonate concentration. Furthermore, he reported that at a treatment pH near 9.0, increased carbonate will increase lead solubility while the reverse pattern will occur at a pH near 6. Bicarbonate concentrations as low as 25 mg/L as $CaCO_3$ will result in a soluble lead concentration of 4.1 mg/L at a pH of 9.3.

Carbonate can be introduced into the system in many ways. One source of carbonate is municipal water supplies. Municipal water supplies in the West, Southcentral, and Midwest regions of the United States have alkalinities greater than 100 mg/L as $CaCO_3$. A second source of carbonate is the atmosphere. Depending upon the equilibrium position (pH and concentration), aqueous solutions not in equilibrium may either evolve or take up carbon dioxide. The equilibrium bicarbonate concentration at a pH of 8.0 is 25 mg/L as $CaCO_3$. The third source of carbonate is carbonate salts used in plating solutions. Examples of these include sodium carbonate, potassium carbonate, and nickel carbonate. The dosages of these salts in solution can be extremely high (e.g., 50,000 mg/L).

The problem of excess carbonate or bicarbonate concentrations can be solved by reducing or eliminating the carbonate concentration by controlling the source or by adding lime to the wastewater and precipitating calcium carbonate. Calcium carbonate precipitation forms a heavier floc which aids in the settling of the lighter lead hydroxide floc.

Mercury

Sulfide precipitation for mercury removal is commonly used. Patterson(13) reported that sulfide precipitation will achieve 99+ percent removal for high initial mercury levels, but the minimum effluent mercury concentration that is achievable with precipitation followed with filtration or activated carbon appears to be 10-20 µg/L. Best results for sulfide precipitation are obtained at pH values less than 9.0. Patterson(13) listed three drawbacks of sulfide precipitation. These are the formation of soluble mercury sulfide complexes at high levels of excess sulfide, the difficulty of monitoring excess sulfide levels, and the problem of toxic sulfide residual in the treated effluent.

Nickel

The theoretical solubility curve for precipitation of nickel as nickel hydroxide was presented in Figure 20. A study conducted by Patterson has shown that experimental results for nickel hydroxide precipitation will be similar to the theoretical results. However, the actual solubility curve for carbonate precipitation will probably be greater than the theoretical carbonate solubility. This anomaly occurs because the kinetics of precipitation for nickel carbonate are very slow and the precipitate will not form within typical treatment plant detention times.(20)

Zinc

The theoretical solubility for zinc hydroxide precipitation is presented in Figure 20. This solubility curve is for a wastewater which is low in carbonate alkalinity. The effect of carbonate either present in the wastewater or induced by the uptake of atmospheric CO_2 is to lower zinc solubility with increased carbonate levels.(20) This effect is especially significant at a pH value less than 9.0 where the presence of carbonate alkalinity can significantly enhance the zinc precipitation process.

Other Metals

Metals other than those discussed in the preceding can be removed from metal finishing wastewates by precipitation. For example, silver may be recovered as the sulfide, although silver hydroxide is relatively soluble.(6) Aluminum may be removed by precipitation as the hydroxide or by phosphate precipitation at pH 5.(15) In point of fact, metal finishing wastewaters may be treated for phosphate removal by addition of aluminum salts and precipitation of $AlPO_4$.

TROUBLESHOOTING GUIDE

The troubleshooting guide for the metal precipitation process is presented in Table 11. The problem areas in the metal precipitation process involve too high a concentration of soluble metal in the effluent (which often traces to inadequate pH adjustment or control) and too high a concentration of particulate metal in the effluent (which usually traces to the solids separation system). In the case of sulfide precipitation processes, sulfide odors may arise due to improper concentrations of the sulfide salt or too short a reaction time.

TABLE 11
METAL PRECIPITATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Total metal concentration in final discharge is too high.			
1a. Soluble metal concentration in discharge is too high.	- Compare soluble metal concentration for pH adjustment process to soluble concentration for plant discharge.	- Shifts in pH of wastewater from pH adjustment to final discharge will affect metal solubility.	- If soluble metal concentration of pH adjustment process is low and within permit, then operation of pH adjustment is acceptable, and cause of problem is solids separation. See Probable Cause (c). - If soluble metal concentration of pH adjustment process is high and out-of-spec, then see Probable Cause (b).
1b. Soluble metal concentration in pH adjustment discharge is too high.	- Check operating problems for the pH adjustment process.	- The problems listed for pH adjustment (see Table 9) can result in soluble metal concentration that is too high.	- Perform corrective action as identified in Table 9.
	- Check operating pH of pH adjustment process.	- The operating pH may not be at optimum pH for precipitation.	- Review or develop pH-solubility diagram for metal. Changing the operating pH of the system can affect precipitation of other metals.
	- Analyze pH adjustment discharge for high concentration of ions.	- Ions, especially phosphates and carbonates, can alter solubility of metal ions.	- Coprecipitate ions in treatment process with lime or other precipitation reagents; eliminate ions that cause problem from wastewater.
OPERATING PROBLEM 2: Particulate metal concentration in final discharge is too high.			
2a. Floc carryover.	- Poor operation of flocculation system.	- Operation of flocculation system must enhance sedimentation.	- Perform corrective action in Table 13.
	- Poor performance of sedimentation system.	- Sedimentation units should remove most of insoluble precipitate formed in pH adjustment process.	- Perform corrective action in Table 15.

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TABLE 11
(Continued)
METAL PRECIPITATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
	- Poor performance of filtration system (if provided).	- Filtration units should polish the discharge from sedimentation system.	- Perform corrective action in Table 17.
	- Shifts in pH of the wastewater from pH adjustment process to final discharge.	- Shifts in pH of the wastewater (especially across the post neutralization tank) from the pH adjustment to final discharge will affect metal solubility and, hence, particulate metal concentration.	- If changes in pH occur, then analyze soluble metal concentration for pH adjustment discharge and final discharge. Refer to Probable Cause 1a.
OPERATING PROBLEM 3: Sulfide odor in effluent.			
3a. Too high a concentration of sulfide salt used.	- Sulfide application rate.	- Too high a concentration or too short reaction time will cause sulfide odors.	- Modify sulfide precipitation procedures. Decrease sulfide application rate.

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SECTION 10

FLOCCULATION

INTRODUCTION

Flocculation is the process whereby particles are gently agitated to enhance particle agglomeration. The purpose of flocculation is to increase the size of the floc because larger floc particles settle faster than smaller floc particles. The flocculation process generally follows the pH adjustment process which generates the flocculant particles and precedes the sedimentation or filtration process which removes the flocculant particles from the wastewater. Flocculation of particles can be accomplished in tanks, basins, or in pipes. Polymers, which are used extensively to enhance the particle agglomeration for metal finishing wastewaters, are typically added in the flocculation tank or basin.

THEORY OF OPERATION

The key to flocculation is to promote particle contact and agglomeration without providing excess agitation that will shear the floc into smaller particles. Agitation should be carefully monitored and controlled so that the floc particles will not be sheared. The amount of agitation in a flocculation tank can be determined by calculating the mean velocity gradient. The mean velocity gradient is a function of the power input, the basin volume, and viscosity of the water.

In addition to depending upon proper agitation, particle contact and agglomeration will also depend upon the size of the particles and their charge in solution. Coagulants are added because they destabilize the particles in solution by altering the charge of the particles and bridging small particles into masses or flocs. Generally the larger the size of the floc, the faster the particles will settle. Both inorganic metal salts and organic polymers are used to aid in particle settling. Some of the inorganic chemicals used are aluminum sulfate (alum), ferric chloride, ferrous sulfate, and lime.

Determination of the best coagulant for a given system should be based upon jar tests and scale-up factors. Jar tests are a series of bench scale tests which can be employed to simulate chemical addition, floccuation, and clarification. A "gang stirrer" is commonly used to perform four to six jar tests at one time. Each jar test is subjected to one different condition from the prior test, such as polymer dosage. When performing a jar test, the operating condition of the test should simulate the conditions in the field. The conditions of the full-scale flocculation/clarification system which should be duplicated by the jar test include similar dilutions of the concentrated polymer, similar HRT, and similar mixing intensity of the flocculation/clarification system. The procedure for jar testing for emulsion breaking presented in Section 5, Oil Removal, are applicable with only minor modification to coagulation processes.

Chemical coagulants are used extensively in the treatment of metal finihsing wastes. However, the type and dosage of the coagulant commonly are not optimized. This failure to optimize the system can cause increased chemical cost and/or poor performance. The operator should perform a series of jar tests to determine the optimum dosage whenever the wastewater characteristics change. Every six to twelve months, the operator should evaluate different coagulants in order to select the most cost-effective coagulant.

DESCRIPTION OF EQUIPMENT

Flocculation of particles is promoted by gently stirring the wastewater. There are several methods which range from simple, inexpensive

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devices to large pieces of equipment for flocculation. Three types of flocculation equipment commonly used are in-line mixers, reactor-clarifiers, and flocculation basins. In-line or static mixers are simple devices mounted in the pipe. A bypass which will allow for the in-line mixer to be taken out of service should also be provided.

Flocculation can be an integral part of a clarifier (reactor-clarifiers). This system is accomplished by providing an inlet well with a mechanical mixer. Variable speed mixers allow the operator flexibility in controlling the mixing intensity.

Flocculation basins are used for systems which require long mixing periods or for systems in which it is necessary to vary the mixing intensity within the basin. Long mixing periods are desired for slow reacting reagents such as limestone. Flocculation in the tank is usually provided by mechanical mixers but can be provided by either stationary baffles or diffused air.

OPERATIONAL PROCEDURES

To control the operation of the flocculation process, the operator should conduct the necessary process monitoring, perform any control calculations needed, and understand the process control strategies or variables.

Process Monitoring

The primary parameters which should be monitored to control the flocculation process are power input and polymer dosage. Other parameters which should be measured for the polymer system include optimum dosage (e.g., by jar testing) and polymer type. These monitoring requirements are shown in Table 12.

In addition to heeding these requirements, the operator should inspect the flocculation system regularly. The operator should inspect

TABLE 12

FLOCCULATION
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Polymer Dosage	Regularly	- Dosage should be determined at least hourly.
2. Polymer Jar Tests	Daily	- Jar tests should be performed daily to determine optimum dosage.
3. Polymer Type	Occasionally	- Jar tests should be performed occasionally to select best polymer when process problems dictate.
4. Polymer Feed Concentration	For each batch	- Concentration should be calculated and must not exceed manufacturer's recommendations.
5. Flocculation Horsepower	Occasionally	- Velocity gradient should be calculated occasionally so that correct power is applied.

mixing baffles and look for hydraulic short-circuiting, torn impellers, or solids accumulation. Any deficiencies should be corrected immediately.

Example Calculations

Example calculations are shown below for determining the mean velocity gradient and the polymer dosage.

Mean Velocity Gradient --

The mean velocity gradient (MVG) is a function of the mixing intensity or mixing horsepower. The mathematical formula for MVG is as follows:

$$MVG = \left(\frac{P \times 550}{mV} \right)^{1/2}$$

where MVG = mean velocity gradient (sec^{-1})
P = power input (Hp)
m = dynamic viscosity ($lb\text{-}sec/ft^2$)
V = flocculator volume (ft^3)

Consider a flocculation system with the following characteristics: Horsepower = 12 Hp, Viscosity = 2.05×10^{-5} $lb\text{-}sec/ft^2$, and Volume = 75,000 ft^3.

$$MVG = \left(\frac{12 \times 550}{2.05 \times 10^{-5} \times 75{,}000} \right)^{1/2}$$

$$MVG = 66/sec$$

Polymer Dosage --

The polymer dosage can be determined from the following formula:

$$PD = \frac{q \times C}{6000 \times Q} \times 10^{6}$$

where: PD = polymer dosage (ppm)
q = polymer flowrate (gal/hr)
C = polymer concentration in solution feed (%)
Q = wastewater flowrate (gpm)

Consider the following example: Polymer flowrate = 2.0 gal/hr, Polymer concentration = 0.5%, and Wastewater flowrate = 10 gpm. The polymer dosage will be

$$PD = \frac{2.0\ \text{gal/hr} \times 0.5}{6000 \times 10} \times 10^6$$

$$= 16.7\ \text{ppm}$$

Process Control Strategies

The two primary adjustments controlling the flocculation process are mixing intensity and polymer addition. The operator should determine the optimum set points for these adjustments based on the settling ability of the flocculant particles.

Mixing Intensity--

The operator should control the mixing intensity such that the desired level of agitation between metal particles and polymer is achieved. The correct amount of agitation will result in particles that settle rapidly and do not require high dosages of polymer. Under-agitation between particles and polymer will result in the formation of very small floc particles that do not settle readily. Under-agitation of the flocculation process may be caused by not providing sufficient power or not allowing enough time for particle/polymer contact.

The power input to a flocculation basin should be controlled to obtain a mean velocity gradient between 20 and 75 sec^{-1} for a 15 to 30 minute detention time. High velocity gradients should be used for shorter detention times and low velocity gradients should be used for longer detention times. Polymers should be added to the inlet or further upstream of the floculation basin to achieve maximum contact.

Under-agitation for in-line mixers is a result of not providing sufficient head loss through the mixer. The minimum pressure drop for most in-line mixers should be approximately one foot of head for a fluid velocity between 1 and 2 feet per second (fps). For most systems, a four or six element in-line mixer will be adequate. Lower element mixers should be used for systems where there are changes in the direction of flow from the mixer to the settling device.

Over-agitation of the wastewater may shear the floc into smaller particles which also will not settle. Too much agitation may be caused by operating the flocculation paddles at too high a speed or by using a centrifugal pump to pump flocculated wastewater. Also over-agitation may be caused by high velocities in the pipe or the inlet to the clarifier.

Polymer Addition--(24,35,26,27)

Polymers used as coagulants in wastewater treatment can be either synthetic or natural. They are composed of many small compounds (monomers), which can be identical to each other, or of different materials. Polymers are chains of monomers whose number is varied by reaction to produce polymers with different molecular weights; those used in wastewater treatment normally range from 100,000 to 1,000,000. Their prime function is to act as a "coagulant aid," a term applied to chemicals such as lime that are added to wastewater, in addition to conventional coagulants, to improve colloidal destabilization and flocculation.

The term "polyelectrolyte" is used to describe chemicals of charged groups in the form of a polymer. The polyelectrolytes are further classified according to the type of charge they will have in solution, as follows:

Anionic Polyelectrolytes-negative charges
Cationic Polyelectrolytes-positive charges
Nonionic Polymers (Nonionic Polyelectrolytes)-neutral charges

The variety of monomers available as buildling materials for polymers is endless, meaning that there is a large assortment of polyelectrolytes available for use in coagulation.

Polymers can be purchased dry or in liquid form. They are easily handled at the plant site and are generally nonhazardous. The usual protection from dust is required, and the storage facilities for the dry powders must be moisture-free. The materials of construction for storage and handling equipment are normally stainless steel 316 and plastics; selection is made on the basis of the polyelectrolyte chosen.

The coagulation mechanisms of polyelectrolytes are associated with charge reduction of the colloids, which results in absorption or enmeshment of the individual particles to form a settleable mass. Due to the size of the polymeric compound, the polymers can attach themselves to the surfaces of the suspension at one or more sites. The excess part of the polymer chain extends into the solution and absorbs onto other particles. The size of the floc being formed is generally restricted by the strength of the attractive forces between the particles and those between the solids and the stream.

Polyelectrolytes are used extensively in coagulation processes because of their versatility, range of properties, handling ease, and effect on coagulation rates. Generally, cationic polyelectrolytes are used alone or as aids to other coagulants in forming metallic salts. Anionic polymers are used as coagulant aids in colloidal destabilization where negative charges are required to bridge the positvely charged colloids. Nonionic polyelectrolytes are added to increase floc size by attaching themselves to agglomerated colloids.

Polyelectrolytes will:

- Increase the size and stability of the flocs;
- Decrease dosages of conventional chemical coagulants, such as alum;
- Decrease floc formation time;
- Extend the effective range of coagulant dosage;
- Extend range of pH over which conventional coagulants are effective; and
- Increase suspended-solids removal efficiencies.

In actual plant use, liquid polymers are usually diluted to approximately a 1% solution (vol/vol). This is done by adding one part (by volume) of polymer to 100 parts (by volume) of water. Dry polymers are usually diluted to approximately a 0.1% solution, (wt/wt). This is done by adding one part of dry polymer (by weight) to 1000 parts of water (by weight). An example of a 1% solution of liquid polymer is to add one gallon raw polymer to 100 gallons of water. To prepare the same solution for a jar test one adds one milliliter of liquid polymer to 100 milliliters of water. An example of a 0.1 % solution of dry polymer would be to add .834 lbs of polymer to 100 gallons of water (834 lbs). To prepare a 0.1% solution for a jar test one adds one gram of polymer to one liter of water (1000 grams). Polymer solutions in excess of these concentrations may be difficult to mix or to pump.

Polymers vary widely as far as their shelf life is concerned and mixed polymers often lose their effectiveness in as short a time as one day. It is recommended that only enough polymer to last for one day's run time be mixed. The method used to add polymer to water and mixing times used are critical. A recommended procedure is to fill the mixing tank to about 3/4 of desired level and start mixers and add polymer very slowly. After all the polymer is added, the tank is filled to the desired level and mixed for a minimum of 30 minutes. Mixing times vary widely for different polymers so one is advised to check with the polymer manufacturer for detailed information.

Different polymers are often not compatible. If polymers being used are changed, all lines and pumps should be thoroughly flushed out, as should mix tanks and day tanks, before the new polymer is added.

Polymers should be protected from extreme changes in weather and so should be stored inside.

Handling, storage, and feed-flow control facilities are as important as proper selection of coagulants and determination of the coagulant dosage. The wrong coagulant dosage can adversely affect the settling and flocculation rates of suspended solids by causing the colloidal suspension to restabilize. Low coagulant concentrations have similar effects.

A data sheet should be completed when performing jar tests. The data sheet contains the various parameters and observations which are important when performing a jar test.

TYPICAL PERFORMANCE VALUES

The performance of the flocculation process can be measured by how well the flocculant particles settle or are filtered. A well operated flocculation process will generally require low dosages of coagulants and will produce low concentrations of suspended solids in the effluent.

TROUBLESHOOTING GUIDE

The troubleshooting guide for the flocculation process is presented in Table 13. The chief problem of the flocculation process is poor settling floc, which may be caused by under-agitation, overagitation, or improper polymer use. Improper polymer use may include the use of an ineffective polymer or the improper application of an otherwise effective polymer.

TABLE 13
FLOCCULATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Poor settling floc.			
1a. Underagitation (Tanks or Basins)	- Calculate mixing intensity of basin or tank.	- Inadequate power will not provide correct particle/polymer contact.	- Increase horsepower.
	- Check tank baffles and mixer impeller.	- Worn or broken baffles and impeller will cause underagitation.	- Repair baffles and impeller as needed.
	- Calculate theoretical detention time of basin or tank.	- Sufficient detention time required for particle/polymer contact.	- Increase detention time by reducing flowrate at the equalization basin (if possible).
	- Observe basin for short-circuiting.	- Short-circuiting due to accumulation of solids or improper placement of inlet and outlet structures may reduce detention time.	- Remove solids or relocate inlet and outlet structures if possible.
1b. Underagitation (In-line mixing)	- Check operation of inline mixers.	- Worn or torn elements may reduce mixing capactiy.	- Repair/replace as necessary.
	- Determine number of changes in direction of flow due to number of elements for in-line mixer plus number of bends in piping.	- Four to six or more changes in direction of flow (velocity = 1 to 2 fps) are recommended minimum.	- Add more in-line mixing by adding more changes in direction of flow (Add in-line mixer or bends in piping.)
1c. Overagitation (Tanks or Basins)	- Calculate mixing intensity in basin or tank.	- Excessive power input may shear flocculant particles.	- Reduce horsepower.
	- Determine impeller speed or RPM.	- Excessive impeller speed may shear flocculant particles.	- Contact agitator manufacturer to determine correct impeller speed for particular application.
	- Look for excessive shear forces acting on flocculant particles.	- Excessive shear can be caused by centrifugal pumps or very high pipe velocities.	- Reduce shear forces by replacing centrifugal pumps with positive displacement pumps or replace pipe with larger diameter pipe.

TABLE 13
(Continued)
FLOCCULATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
1d. Incorrect Polymer Addition	- Observe location of polymer addition.	- Improper location of polymer addition will not provide sufficient time for polymer/particle contact.	- Relocate polymer addition location.
	- Determine concentration and shelf life of polymer solution.	- Incorrect polymer solution concentration or too long a solution storage time can reduce effect of polymer addition.	- Make-up new polymer solution at correct concentration or be sure storage time of prepared solution is short.
	- Perform jar tests to determine optimum polymer dosage.	- Compare dosage determined from jar tests to dosage of full-scale system.	- Adjust polymer solution flowrate to achieve optimum dosage.
	- Perform jar tests to determine optimum coagulant type.	- Optimum coagulant will depend upon jar test results, cost, and applicability to full scale system.	- Select new coagulant.

SECTION 11

SEDIMENTATION

INTRODUCTION

Particles or suspended solids which are generated in pH adjustment and flocculation processes can usually be separated effectively from the wastewater by gravity separation or sedimentation. Since the settling characteristics of flocculant particles will vary with the system, the operation of a sedimentation unit should be based on an understanding of the theory of the sedimentation process and the variables which affect its efficiency.

THEORY OF OPERATION

Settling basins handling wastewater must separate a variety of types of materials in the clarification zone. These materials vary from discrete particles at relatively low concentrations to suspensions of highly flocculent solids at elevated concentrations levels. For purposes of discussion these materials are divided into three general classes:(22)

1. Class I materials;
    (a) discrete particles,
    (b) settling rate independent of concentration, and
    (c) settling rate equal to overflow rate.
2. Class II materials;
    (a) particle growth,
    (b) overflow rate and detention time critical, and
    (c) rate of particle growth important.

3. Class III materials;
   (a) high suspended solids concentration,
   (b) settling rate is a function of the concentration, and
   (c) detention time and solids loading important.

Sedimentation of Class I suspensions is at a constant rate throughout the sedimentation basin and is, therefore, independent of depth. These are discrete particles which will not flocculate, for example, grit particles.

Sedimentation for Class II type suspensions occurs when larger particles settle at faster rates than smaller particles and overtake the smaller particles in their descent. If the particles have characteristics which might cause agglomeration, then growth of the finer particles to larger ones will occur. The greater the tank depth, the greater is the opportunity for contact among particles. Therefore, removal of suspended solids will be dependent upon basin depth as well as properties of the particles and fluid. The growth of individual particles enhances removal rates because larger particles create a reduced surface-area-to-mass ratio and thus the drag forces opposing subsidence are reduced. Polymer addition is normally required to improve particle agglomeration.

Class III suspensions are characterized by relatively high concentrations of material. The material may be flocculent, but not necessarily so. "Hindered settling" is the term generally used to describe Class III solids separation. An example of this type of separation may be found in activated sludge settling with high MLSS. Design of settling basins for Class III suspensions must consider hydraulic as well as mass surface area loading.(22)

DESCRIPTION OF EQUIPMENT

The equipment used in gravity sedimentation includes clarifiers, parallel plate or tube settlers, and lagoons. The function of this equipment is to provide quiescent conditions to permit the heavier-than-water particles to settle.

There are many types of gravity clarifiers in service today. Conventional clarifiers vary in complexity but generally consist of a circular or rectangular tank with a mechanical sludge collecting device or with a sloping funnel-shaped bottom designed for sludge collection. Reactor clarifiers combine flocculation and sedimentation in one unit.

Parallel or tube settlers utilize a series of inclined settling plates in close proximity to each other. The inclined plate concept provides the effective surface area of each plate as projected onto the horizontal surface. This arrangement provides a higher effective surface area for a given horizontal surface. Since settling of metal finishing suspended solids is a function of the effective surface area, increasing this area by adding inclined plates allows the horizontal surface to be reduced. Therefore, the total horizontal surface area required for parallel or tube settlers will always be less than that for conventional gravity clarifiers.

Lagoons are also used for gravity settling. The advantage of a lagoon is that very little maintenance is required other than periodic sludge removal. However, appropriate disposal of the sludge is required; recent solid waste regulations can make effective lagoon operation an expensive procedure.

OPERATIONAL PROCEDURES

To control the operation of the sedimentation process, the operator should conduct the necessary process monitoring, perform any control calculations needed, and understand the process control strategies or variables. The operator also should understand how the design of the sedimentation equipment will affect treatment performance.

Process Monitoring

The performance criterion for evaluating sedimentation equipment is effluent total suspended solids concentration. While this parameter assesses the overall performance of the system, several other parameters must be measured and incorporated into a regular monitoring program to operate a sedimentation system successfully and consistently. The parameters of importance are listed in Table 14.

The influent or effluent wastewater flowrate must be monitored to determine the solids loading and the hydraulic loading to the clarifier. If either the solids loading or the hydraulic loading to the clarifier is greater than the design value, then the performance of the process may decline significantly. Example calculations for determining the solids loading and the hydraulic loading (surface overflow rate) are discussed in the following section.

The influent TSS concentration should be measured to determine the influent solids loading and the effluent TSS concentration should be measured to determine removal performance. In addition to these analyses, the sludge depth and sludge suspended solids concentration should be measured so that a mass balance for suspended solids around the sedimentation basin can be determined. A mass balance is important for estimating sludge wasting rates and for adjusting the timer which controls operation of the sludge wasting pumps. It is essential that the samples collected for the mass balance analyses be flow proportional.

Example Calculations

Several computations should be made by the operator to measure the performance of a sedimentation unit. These calculations are surface overflow rate, solids loading rate, and mass balance. These calculations can be made with minimal effort and are helpful to the operator in avoiding and anticipating problems.

Surface Overflow Rate--

The surface overflow rate of a sedimentation unit is defined as the flowrate divided by the effective surface area.

$$\text{Surface Overflow Rate (GPD/Ft}^2) = \frac{\text{Flowrate (GPD)}}{\text{Effective Surface Area (Ft}^2)}$$

TABLE 14

SEDIMENTATION
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Wastewater Flow	Continuously	To determine surface overflow rate and TSS loading.
2. Influent and Effluent TSS	Daily	To measure efficiency and TSS loading.
3. Sludge Level	Daily	To determine volume of sludge that must be wasted/disposed.
4. Sludge Solids Concentration	Daily	To determine solids loading to disposal equipment.
5. Temperature	Occasionally	Temperature can affect performance.
6. pH	Occasionally	pH affects the coagulation ability of many polymers and inorganic coagulants.

When calculating the surface overflow rate, only the effective surface area should be included in the calculation. The effective surface area is the area in which settling occurs and does not include inlet or outlet zones or dead space. Furthermore, the effective surface area for tube settlers or parallel plate separators should include the sum of the surface area of the plates projected on the horizontal surface.

The following calculation is offered as a guide for determining surface overflow rate.

Given: Flow = 126,000 gallons per day
No. of Tanks = 2
Area of each Tank = 100 ft^2

Surface Overflow Rate (SOR) is calculated as

$$\text{SOR } (\text{GPD/Ft}^2) = \frac{\text{Influent (GPD)}}{\text{Total Tank Area } (\text{Ft}^2)}$$

$$= \frac{126{,}000 \text{ GPD}}{2 \times 100 \text{ Ft}^2}$$

$$= 630 \text{ GPD/Ft}^2$$

Solids Loading--

Even though the settling basin design may meet the hydraulic loading criterion, it is still possible for overloading to occur on a solids basis. Solids overloading occurs when the solids loading to the clarifier exceeds the ability of the clarifier to transport solids to the bottom of the basin. The maximum solids loading for a settling basin generally will be a function of sidewater depth, overflow rate, and feedwell sizing.

Solids loading is determined by the following equation:

$$\text{SL} = \frac{Q \times C \times 8.34}{\text{SA}}$$

where

SL = Solids loading (lbs/day/ft^2)

Q = Influent flowrate (mgd)

C = Influent suspended solids concentration (mg/L)

SA = Effective surface area (ft^2)

Material Balance--

A suspended solids mass balance should be calculated around the sedimentation process to detemine if sufficient solids are being removed. The amount of sludge that should be removed from the sedimentation tank is the difference between the amount of solids entering the clarifier and the amount of solids leaving the clarifier.

This is shown mathematically as:

Mass to remove = Influent Mass - Effluent Mass

$$Q_R C_R = Q_i C_i - Q_e C_e$$

where Q_i = Influent Flow Rate to Clarifier (gpm)
Q_e = Effluent Flow Rate from Clarifier (gpm)
Q_R = Sludge Removal Flow Rate (gpm)
C_i = Influent Wastewater TSS concentration (mg/L)
C_e = Effluent Wastewater TSS concentration (mg/L)
C_R = Sludge TSS concentration (mg/L)

Also, a mass balance on flow gives the fact that flow out is equal to flow in minus the sludge removal rate, or $Q_e = Q_i - Q_R$.

Since $Q_e \approx Q_i$ for systems where the influent flowrate is much greater than the sludge removal flowrate,

$$Q_R C_R = Q_e (C_i - C_e)$$

or

$$Q_R = \frac{Q_e (C_i - C_e)}{C_R}$$

An example problem which determines the sludge removal rate is:

Given: Influent TSS concentration = 550 mg/L

Effluent TSS concentration = 30 mg/L

Sludge removal TSS concentration = 20,000 mg/L

Plant Flow Rate = 90 gpm

Find: Sludge Removal Flow Rate

$$Q_R = \frac{Q_e (C_i - C_e)}{C_R}$$

$$Q_R = \frac{90 \text{ gal/min } (550 \text{ mg/L} - 30 \text{ mg/L})}{20{,}000 \text{ mg/L}}$$

$$Q_R = 2.3 \text{ gal/min}$$

The amount of sludge to be removed will be a function of the sludge concentration (C_R) and the sludge removal flow rate (Q_R). The greater the sludge concentration is, the lower the sludge removal rate will be. Conversely, the lower the solids concentration is, the greater the sludge removal rate will be. The concentration of the sludge will change with changes in influent loading (Q_i and C_i), effluent quality (C_e), and sludge removal rates. The operator should find the sludge removal flow rate which will not hydraulically overload the downstream dewatering units and which is high enough such that the sludge does not remain in the clarifier sedimentation tank for periods longer than a few hours. Allowing sludge to remain in the clarifier for long periods may cause the sludge to become cementous. Excess sludge in a clarifier increases the torque on the clarifier rake. High torque in the clarifer will actuate the torque limit switch which will turn off the clarifier rakes.

Process Control Strategies

Based on the monitoring data collected and the values calculated for surface overflow rate, solids loading, or mass (material) balance, the operator can adjust several variables of clarifier operation to meet permit requirements. The important variables in the operation of a sedimentation basin are sludge wasting, solids loading, hydraulic loading, and chemical addition.

Sludge Wasting--

The sludge wasting rate or sludge removal volume should be adjusted so that sludge does not accumulate in the clarifier. The operator should adjust the sludge wasting rate so that the mass of sludge removed is equal to the difference between the influent mass of suspended solids and the effluent mass of suspended solids. An example of this calculation is presented in the "Material Balance" section discussed previously. The two types of sedimentation systems in which solids overloading are most likely to occur are parallel plate or tube separators and sludge recirculation systems. Solids overloading can occur in tube settlers due to plugging of the tubes. If this happens frequently, the operator should backwash the tube settlers more often in order to eliminate plugging.

Solids overloading can also be caused by not wasting enough sludge from the clarification system. This condition usually occurs in systems that employ sludge recirculation, but can occur if sludge is allowed to build up in the clarifier. The operator should calculate solids loading from the equation presented above. If the solids loading exceeds the maximum value, the operator should waste sludge from the clarifier or should decrease the flowrate temporarily.

Hydraulic Loading Capacity--

In addition to adjusting the flow rate to control the solids loading to the sedimentation unit, the operator should control the flow rate to the sedimentation process so as not to exceed its hydraulic loading capacity, if possible. The hydraulic loading of a sedimentation basin is generally determined by the surface overflow rate calculation (see preceding discussion). The maximum hydraulic capacity of a sedimentation unit or clarifier will be dependent upon the type of clarifier, the settling characteristics of the particles, and the chemical coagulants used.

Surface overflow rates of 600 to 2880 gpd/ft^2 are recommended for calcium carbonate precipitate. Lower rates (600-1800 gpd/ft^2) are recommended for aluminum and iron floc(21). Generally higher overflow rates are used for lime precipitation because of favorable settling characteristics. Lower overflow rates are employed for small systems and for systems which use caustic or soda ash for pH adjustment. The hydraulic loading capacity for a particular clarifier should be based on a relationship between flow rate and effluent suspended solids that has been calculated from actual operating data. If the operator determines that flows in excess of a given flow rate will cause treatment problems, then the operator should take steps necessary to reduce the flow rate.

The most practical way to control the flow rate is with a variable level equalization tank or surge tank. However, peak flow rates can be minimized by scheduling tank washdowns and clean-ups during periods of low hydraulic loading.

Coagulant Addition--

The operator can control the settling rate of particles by adjusting the coagulant or polymer addition system. The polymer addition variables which can affect settling are polymer type and dosage, point of injection, and flocculation. The operator should refer to the troubleshooting table for flocculation (see Table 13) for adjusting the polymer addition system.

Design Characteristics

The performance of sedimentation equipment will depend upon operating variables such as influent flow, sludge wasting, and polymer addition, but will also depend upon factors beyond the control of the operator. These factors can be a function of either the wastewater characteristics or the design of the system. Generally, proper sedimentation of the wastewater will result in suspended solids concentrations of less than 50 mg/L.

The factors which are associated with the design of a sedimentation basin are discussed below.

Flow Variations--

Flow variations can be caused by extremes in instantaneous flows or by a constant speed pump cycling on and off. High instantanous flows can be reduced with equalization, elimination of storm water inflow/infiltration, or reduction of the rate at which high volume wastes are discharged.

Cycling on and off of a constant speed pump can cause pulsating turbulence in the clarification zone and can damage the pump and motor. A number of solutions are available to correct this problem. Part of the discharge from the pump can be recycled back to the pump sump or the pump can be throttled with a valve. Other solutions include replacing the constant speed pump with a variable speed pump and adding a smaller capacity constant speed pump.

Inlet Design--

The Manual of Practice for Wastewater Treatment Plant Design reports that next to the importance of proper sizing of a settling tank is proper inlet design. The inlet to a sedimentation basin must be an effective arrangement to achieve horizontal and vertical distribution of the flow across the entire cross-sectional flow-through area. The inlet design must also dissipate the inlet energy. The maximum inlet velocity to the center inlet well should not exceed 3 fps and the outflow velocity should not exceed 15 feet per minute.(22)

In order to dissipate energy readily, clarifier inlets are normally equipped with baffles or small ports. Inlet ports should be sized for velocities in the range of 15 to 30 fpm. Baffles should extend from a point several inches below the water surface to a point 6-12 inches below the inlet point.(22)

Density Currents--

Short-circuiting can occur in sedimentation basins if the incoming flow has a higher temperature or density than the mass of liquid in the basin. This condition is usually evidenced by violent rolling of masses of liquid with entrained solids to the surface. Short-circuiting can occur when the temperature suddenly increases 1 to 2°C with light flocculant-type solids.(22)

Temperature increases can be especially significant during startups. Control over density currents is achieved by limiting the temperature change to 1-2°C over a period of at least an hour. One method for eliminating temperature gradients in the sedimentation basin is to recycle the clarifier underflow back to the treatment processes.(22)

Outlet Design--

The overflow or effluent takeoff weir should be designed and operated such that the clarifier liquid can be removed from the basin without causing localized high velocity up-drafts. These updrafts cause previously settled solids to be carried over the weir. For this reason most sedimentation basins have a sidewater depth between 8 and 12 feet.

In order to eliminate short circuiting caused by localized velocity up-drafts, a multiplicity of weirs is recommended. The Ten States Standards suggested a limit of 15,000 gpd/ft^2 for secondary settling basins.(23)

Tank Depth--

The depth of a tank will affect performance by affecting particle contact. Since settling of flocculant particles is affected by tank depth, a greater tank depth will produce higher removal efficiencies.

TYPICAL PERFORMANCE VALUES

Sedimentation of flocculant particles from metal finishing wastewater treatment should result in suspended solids concentrations less than 50 mg/L.

TROUBLESHOOTING GUIDE

The troubleshooting table for the sedimentation process is presented in Table 15. Several types of problems are addressed; these include high sludge blanket, high solids concentration in the effluent, flow short-circuiting, mechanical torque problems in the equipment, deflocculation in the clarifier, and high metals concentration in the effluent. Many of the potential solutions involve correction of mechanical problems.

TABLE 15
SEDIMENTATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Sludge blanket overflow weirs.			
1a. Sludge blanket too high.	- Depth of sludge blanket. Operation of sludge pump.	- Sludge not being removed at fast enough rate.	- Increase removal rate of sludge from clarifier.
OPERATING PROBLEM 2: Sludge blanket too high. Sludge removal pumps operating properly.			
2a. Defective scraper blades on bottom sludge scrapers.	- Bottom sludge scraper blade.	- Scraper blade out of adjustment or broken. Sludge not being moved to clarifier hopper.	- Drain clarifier and adjust or repair scraper blade.
OPERATING PROBLEM 3: Excessive torque on rake mechanism.			
3a. Sludge blanket too high. Sludge concentration too high.	- Depth of blanket and sludge concentration.	- Thick sludge can cause torque overload.	- Increase removal rate of sludge. Blanket depth will have to be decreased rapidly to prevent damage to clarifier.
3b. Foreign object in clarifier.	- Bottom of clarifier for foreign objects.	- Foreign object can wedge scraper and cause torque.	- Drain clarifier and remove object.
3c. Bottom sludge scraper out of adjustment.	- Bottom scraper arm adjustment.	- Scraper blades touching bottom causing torque overload.	- Drain clarifier and readjust bottom scaper arm and/or blades.
3d. Top skimmer out of adjustment.	- Top skimmer.	- Skimmer could be rubbing side walls of clarifier or could have dropped causing excessive torque as skimmer passes over skimmings hopper.	- Adjust blade on end of skimmer arm. - Adjust baffle of clarifier if out of round. - Readjust position of top skimmer.
3e. Mechanical problems.	- Gear box, bearings, motor.	- Excessive drag due to mechanical problems can cause torque problems.	- Replace or repair defective part.

TABLE 15
(Continued)
SEDIMENTATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 4: High TSS concentration in clarifier effluent.			
4a. Sludge blanket too high.	- See Steps 1 and 2.	- See Steps 1 and 2.	- See Steps 1 and 2.
4b. Influent flow too high.	- Flow rate to clarifier.	- Excessive flow rates will cause solids carryover.	- Reduce flow rate.
4c. Chemical dosage wrong.	- Chemical dosage.	- Low or high chemical dosage can cause solids carryover.	- Run jar test. Readjust dosage.
4d. Sludge hopper on clarifier for floating solids plugged.	- Exit lines of sludge hopper.	- Plugged hopper will cause increased concentration of floating solids. Solids will overflow weir.	- Unplug hopper.
4e. Poor mixing of wastewater and chemicals.	- Chemical injection point.	- Point of entry of chemicals is critical to proper mixing.	- Inject chmicals at proper point.
	- Turbine drive on reactor clarifiers.	- Drive may be too fast or too slow.	- Readjust speed of turbine drive.
4f. Short circuiting of clarifier flow.	- Level of clarifier weirs.	- Uneven weirs causes short circuiting.	- Level weirs.
4g. Solids concentration to clarifier too high.	- Partial blocking of V notch weirs.	- Partial blocking can cause short circuiting.	- Clean weirs.
	- Solids concentration.	- Exceeding solids loading rate will cause solids carryover.	- Decrease solids loading.
OPERATING PROBLEM 5: Short-circuiting of clarifier flows.			
5a. Uneven weirs.	- See Step 4f.	- See Step 4f.	- See Step 4f.
5b. Plugged weirs	- See Step 4f.	- See Step 4f.	- See Step 4f.

TABLE 15
(Continued)
SEDIMENTATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
5c. Excessive hydraulic load.	- Flow rate to clarifier.	- High flow rate will cause short circuiting.	- Reduce flow rate or place additional units in service.
5d. Temperature difference between influent flow and clarifier water.	- Water temperatures.	- Temperature differences can cause short circuiting.	- Reduce hydraulic load.
OPERATING PROBLEM 6: Deflocculation in clarifier.			
6a. Excessive shear.	- Injection point and agitation.	- Excessive mixing or excessive turbulence can cause shear.	- Reduce mixing or agitation.
OPERATING PROBLEM 7: High concentration of metals in effluent.			
7a. Improper treatment prior to sedimentation.	- pH adjustment and metal precipitation.	- Improper chemical treatment will cause metals to remain in solution.	- Correct pH steps. (See pH Adjustment Troubleshooting Guide and Metal Precipitation Troubleshooting Guide.)
7b. Incorrect polymer dosage in clarifier.	- Polymer dosage.	- High or low polymer dosage can allow solids carryover.	- Run jar test and readjust polymer dosage. See Flocculation Troubleshooting Guide.
7c. Sludge blanket too high.	- See Steps 1 and 2.	- See Steps 1 and 2.	- See Steps 1 and 2.
7d. Short circuiting of clarifier flows.	- See Step 5.	- See Step 5.	- See Step 5.
7e. See Step 4.	- See Step 4.	- See Step 4.	- See Step 4.

SECTION 12

FILTRATION

INTRODUCTION

Filtration is a separation process used to remove suspended solids generated by precipitation and other suspended solids present in the wastewater. Generally, filtration is used after clarification to further reduce the suspended solids concentration in the final effluent, thus enabling the treatment system to meet more stringent effluent requirements or to permit the treated wastewater to be recycled. Additionally, filters are sometimes used in treatment systems in which space is severely limited as the sole suspended solids removal process.

In the filtration process, wastewater is passed through a bed of porous material which separates the solids from the wastewater. Depending upon the nature of the filter, one of two different separation processes predominate. In deep granular filters the solids are removed through an adsorption/disposition process as the wastewater passes through a deep bed of granular material. In pre-coat and cartridge filters the solids are removed through a mechanical straining process as the wastewater passes through a thin layer of filter media.

THEORY OF OPERATION

Filtration involves the passage of water through porous media with a resulting removal of suspended solids. A number of mechanisms, some chemical and some physical, are involved in the solids removal process. The predominant mechanisms are straining, disposition, and adsorption.

The dominant mechanism for a given filter depends upon the physical and chemical characteristics of the wastewater and the filter.

Straining involves removal of particles either at the filter surface or within the interstices of the filter media and is affected by the filter media and particle size and the filtration rate. For both precoat filters and cartridge filters, the predominant removal mechanism is assumed to be straining which occurs at the surface of the filter media. Although straining also occurs to a limited degree in deep granular filters, primarily within the interstices of the media, its importance is generally minimized during design because it leads to rapid buildup of head loss which limits the length of filter runs.

Disposition and adsorption within the filter bed are the predominant solids removal processes in deep granular filters. Disposition involves gravitational settling, diffusion, and interception and is affected by the physical characteristics and size of the media, the filtration rate, the fluid temperature, and the size and density of the suspended solids. Adsorption relies upon the attachment of the suspended solids particles to the filter media. The amount of surface available for adsorption is enormous, roughly 3,000 to 5,000 square feet per cubic foot of media. Adsorption relies upon attachment and is affected by use of coagulants, the characteristics of the wastewater (especially particle size), shear strength and driving force, adhesiveness of the suspended solids floc, and the characteristics of the filter media.

DESCRIPTION OF EQUIPMENT

Filtration processes vary in the type of equipment used, the manner that the driving force is applied to the filter, and the method of backwashing.

Types of Filters

The four most common types of filtration equipment used for treatment of metal wastes are granular deep-bed filters, diatomaceous earth filters, cartridge filters, and pressure filters. Deep bed filters consist of a basin or tank with an 18 to 30 inch layer of sand or other fine granular material supported by an underdrain system and operated under either a gravity head or pressure head. Deep granular filters are generally applicable for the removal of suspended solids in the 5-50 mg/L range, but can handle suspended solids concentrations up to 1000 mg/L and provide about a 90 percent solids removal for short time periods.

Pre-coat filters consist of a number of porous septa supporting a thin layer of filter media. The filter medium is generally diatomaceous earth and pre-coat filters generally operate under a pressure head. Pre-coat filters can handle high suspended solids concentrations provided solids concentrations remain constant. Precoat filters can provide up to 98 percent solids removal.

The use of cartridge filters for wastewater treatment is limited to effluent polishing prior to wastewater recycling. Cartridge filters consist of cartridges of porous material that are enclosed in a housing and operated under a pressure head. Cartridge filters are limited to wastewaters with low suspended solids concentrations, but, depending upon the pore size of the filter cartridge, can provide essentially complete removal of suspended solids.

Pressure filters are also generally used for effluent polishing after clarification. Pressure filters consist of sand media enclosed in a housing and operated under a pressure head. Pressure filters can be operated under a constant head or variable head. A variable head is used often to achieve a constant flowrate.

Driving Force

There are three basic filter operating methods, and they differ in the way that the driving force is applied across the filter. These methods are referred to as constant-pressure filtration, constant-rate filtration, and declining rate filtration. For constant-pressure filtration a constant driving force is applied across the filter for the entire filter run. Because filter resistance is lowest at the start, the flow rate is at its peak. As solids are captured, filter resistance increases and the rate of flow decreases. This operating method is seldom used because a large flow equalization basin is required to deal with the change in flow during the filter run.

In constant-rate filtration a constant pressure is applied to the filter, but filter resistance is modulated through control of the flow rate using a flow control valve. At the start of the filter run the flow control valve is nearly closed, then as solids accumulate, the flow control valve is opened to compensate for the increase in filter resistance. While storage capacity is minimized the initial and operating costs for the rate controller are high and water quality is better than with declining rate filtration. The constant rate system is also wasteful of available head because excess head is lost in the controller. Additionally the control valve may set up high frequency surges in the filter bed.

Declining-rate filtration utilizes a bank of filters to moderate the effect of increases in filter resistance. As the filters served by a common header become dirty, the flow through the dirtiest filter drops rapidly, increasing the driving force so that the other filters can handle additional flow from the dirtiest filter. This method provides a more gradual decrease in the rate of flow over the filter cycle and provides a better effluent quality than with constant rate operation. As with constant pressure filtration, a large upstream water storage is needed.

Backwashing

Once filter resistance exceeds the available driving force the accumulated solids must be removed from the filter. In cartridge filters this process requires dismantling of the filter housing and replacement of the filter cartridges. For precoat filters the filter layer is removed from the system by scraping the septa manually or by washing either directly or by a reverse flow. For deep granular filters and pressure filters, the media are washed and returned to service.

Backwashing of deep granular filters involves reversing the flow through the filter at a rate sufficient to expand the filter bed. The deposited material is then dislodged by hydraulic shearing action of the water and abrasion of the grains of filter media. Where cleaning is inadequate, mud balls, masses of filtered solids, develop and over time will grow and sink deeper into the filter bed, increasing head loss and decreasing effluent quality. Where backwash rates are inadequate to thoroughly clean the filter, longer duration backwashes must be used (5 to 10 or at an extreme, 15 minutes) to provide the necessary cleaning. Air scour is often used to assist in backwashing. Deep bed filters can either be backwashed continuously or intermittently.

OPERATIONAL PROCEDURES

The objective of wastewater filtration is to achieve a high capture of suspended solids and to minimize operating and power requirements without constraining wastewater flow. To achieve this objective, the operator should know how to perform the necessary calculations, perform the required process monitoring, and understand the process control variables or strategies.

Process Monitoring

To maintain the desired level of filtration performance, usually measured by effluent suspended solids or metal concentration, the operator should perform the necessary monitoring and understand how the various parameters can be used to diagnose problems. The monitoring required to troubleshoot the filtration process is listed in Table 16. Included in this table are the frequency of analysis and the reason for monitoring the parameter.

The operation performance of the filtration process is defined by the influent and effluent suspended solids, metal concentration or turbidity, and the filtration rate. As a filter run progresses, the captured solids increase the filter resistance and thus either increase the head loss through the bed or decrease the flowrate through the bed. Decreasing the flowrate through the bed will reduce the filtration capacity of the bed. By operating at higher system pressures the rate of flow can be maintained, but with metal hydroxide flocs there is considerable penetration into the filter and breakthrough can occur at relatively low heads. While run lengths can be shortened to maintain a higher rate of flow, the effects of downtime and backwashing become increasingly important. Thus, filter operation focus is on obtaining the longest possible filter cycle that is consistent with minimal solids breakthrough, practical system head losses, and acceptable filtration rates. Floc breakage at higher pressures can be partially compensated for by use of alum or polyelectrolytes to condition the floc prior to filtration.

Example Calculations

The calculation used most often to troubleshoot the filtration process is the filtration rate. The mathematical formula for filtration rate is

$$\text{Filtration rate (gpm/ft}^2\text{)} = \frac{\text{Flow rate (gpm)}}{\text{Surface area of filter (ft}^2\text{)}}$$

Consider the following example calculation. Determine the filtration rate for a system which has two filters and each filter has a 5-foot diameter. The flow rate is 60 gpm.

TABLE 16

FILTRATION
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Influent flow	Continuously	- To determine filtration rate.
2. Influent TSS	Weekly	- To determine mass loading to filters. - To troubleshoot short filter run problem.
3. Effluent TSS	Daily	- To determine filter performance. - To determine whether to backwash filters.
4. Headloss	Continuously	- To determine when to backwash filter.
5. Filter run time	Each run	- To identify short run periods.
6. Backwash flowrate	Continuously	- To optimize backwash flowrate and duration.
7. Filter aid (type and dosage)	Daily	- To optimize type and dosage.
8. Influent and effluent metal concentration	Weekly	- To determine performance.

$$\text{Filtration rate} = \frac{60}{2 \times (\pi \times 5^2)/4}$$

$$\text{Filtration rate} = 1.53 \text{ gpm/ft}^2$$

The recommended filtration rates for granular filters are shown below.

Type	Filtration
Slow Sand	0.02-0.05 gpm/ft^2
Rapid Sand	2.0-6.0 gpm/ft^2
High Rate Mixed Media	6.0-8.0 gpm/ft^2

Higher filtration rates can be obtained with cartridge filters or pressure filters. Generally these filters are limited by a maximum pressure drop across the filter of 60 psi.

While most systems are designed to operate at the correct filtration rate, problems can occur when one or more filtration units are out of service due to backwashing, replacement of media, or broken equipment.

Process Control Strategies

Filter operation is generally automatic and requires limited operator control. Possible process variables are thus limited to filter run time, length and duration of backwash, and chemical conditioning of the influent wastewater.

Filter Run Time--

The length of the filter run is generally determined by the time required to reach a predetermined head loss or is set at a predetermined length of time. Head loss control is the most commonly used because it minimizes backwashing or filter renewal. Increasing the final head loss point allows longer filter runs but results in lower filter rates and possible solids breakthrough. The head loss point setting is also limited by the maximum available system pressure.

Length and Duration of Backwash--

Effective cleaning of the filter media in deep granular filters is very important to successful plant operation. If the bed is not cleaned well, solids can accumulate, leading to bed cracking and the formation of mud balls. Because all filter backwash water must be returned for treatment excess backwashing should be avoided. The actual requirements for backwashing will vary depending upon the nature of the wastewater and filter aids being used.

Chemical Conditioning of Influent--

Filter performance can be improved by adding filter aids such as polymer and/or alum. These act to strengthen the floc, control penetration of the floc into the filter bed, and improve solids capture on precoat filters. As a result final solids are reduced and allowable flow rate can be increased.

The amount of filter aid required varies with influent wastewater characteristics and should be determined through testing. The optimum dose should be based upon desired filter effluent quality at the end of the filter run.

TYPICAL PERFORMANCE VALUES

The performance can be measured by the suspended solids level of the liquid effluent from the filtration process. A well-operated filtration process produces an effluent with low-suspended solids concentrations; removal efficiences of 90 to 99 percent are common.

TROUBLESHOOTING GUIDE

The guide shown in Table 17 should be used to troubleshoot the filtration process. The table has been divided into three sections to

TABLE 17
FILTRATION TROUBLESHOOTING GUIDE
(PRESSURE FILTERS-SAND)

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: High headloss through filter bed.			
1a. Filter clogged with solids.	- Headloss through filter.	- High headloss will indicate that solids are clogging filter and filter requires backwashing.	- Remove filter from service and backwash.
	- Duration of filter run.	- Duration of filter run as compared to other filter runs will indicate if other problems exist.	- If filter run is high compared to others, then refer to 3a, 3e, and 3f.
	- Solids concentration and flow rates to filter.	- Solids concentration and flow rates will indicate if unusual conditions exist in plant that will shorten run time of filters.	- Reduce solids concentration (see Clarification Troubleshooting Guide) or reduce flow-rate.
OPERATING PROBLEM 2: High headloss through filter just backwashed.			
2a. Insufficient backwash of filter.	- Backwash flow rate.	- Insufficient rate of backwash water will not allow solids to be removed from filter.	- Increase backwash flow rate to desired value.
	- Backwash pump. Check impeller clearance. Check for partial blockage of impeller.	- Defective pump is often the cause of loss of flow rate.	- If pump is defective, it will have to be dismantled and repaired.
	- Backwash flow valve.	- Defective flow valve can cause loss of flow.	- Defective flow control valves will have to be dismantled and repaired.
	- Plugging in bottom spargers of filters.	- Plugged spargers can restrict backwash flow into filters.	- Plugged spargers can sometimes be cleared by prolonged backwashing. If this fails, the spargers must be removed and manually cleaned or replaced.

TABLE 17
(Continued)
FILTRATION TROUBLESHOOTING GUIDE
(PRESSURE FILTERS-SAND)

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
	- Defective valves in backwash system.	- Defective valves could restrict backwash flow into filters.	- Check valves for open and closed position. Valves that are not functioning properly will have to be dismantled and repaired.
	- Instrument air pressure to backwash control system.	- Insufficient instrument air pressure to backwash controls or valves can limit the operation of the system.	- Reset individual pressure regulators to proper setting.
	- Suction piping of pumps or screens inside backwash water supply tank.	- A blockage of suction piping or dirty suction screens can cause a loss of backwash flow rates.	- Backflush suction lines of pump. Remove and clean suction screens.
	- Duration of backwash.	- Complete backwash requires specified flow rate for a specified period of time.	- Increase backwash time. Defective timers may have to be replaced.
	- Filter skipping backwash cycle.	- If filter is completely automated a defective circuit can cause the filter to skip the backwash cycle.	- Visually observe a complete filter cycle. Have defective circuits repaired. Backwash cells manually.

TABLE 17
(Continued)
FILTRATION TROUBLESHOOTING GUIDE
(GRANULAR DEEP BED FILTERS)

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: High headloss through filter bed.			
1a. Filter needs backwashing.	- Headloss through filter.	- High headloss will indicate solids accumulating in filter and filter requires backwashing.	- Remove filter from service and backwash it.
OPERATING PROBLEM 2: High headloss through a filter just backwashed.			
2a. Insufficient backwash time to thoroughly clean the filter media.	- Headloss greater than normal and influent suspended solids.	- High initial headloss (1 - 2 ft) even with low suspended solids concentration will cause short filter runs.	- Increase the setting on the backwash timer to provide longer backwash period.
2b. Inoperative surface wash arm (if applicable).	- Visually inspect surface wash arm.	- Surface wash arm must turn freely.	- Repair suface wash arm.
2c. Inoperable air scouring system (if applicable).	- Inspect pressure setting and aeration pattern.	- Pressure setting could be too high or low and air ports could be plugged.	- Adjust pressure to correct setting. - Unplug air ports.
2d. Rapid accumulation of solids on the top surface of the media due to:			
i) Inadequate prior clarification for sand filters.	- Measure influent TSS concentration.	- High TSS concentration will reduce filter run time.	- Improve clarification performance.
ii) Excessive filter aid dosages in dual or mixed-media filters.	- Evaluate filter aid dosage and type.	- Filter aid dosage and type will affect rate of headloss build-up.	- Reduce or eliminate filter aid dosage.

TABLE 17
(Continued)
FILTRATION TROUBLESHOOTING GUIDE
(GRANULAR DEEP BED FILTERS)

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 3: Short filter runs.			
3a. See Item 2d.	- See Item 2d.	- See Item 2d.	- See Item 2d.
3b. Insufficient filter backwash.	- Check backwash rate and duration.	- Low backwash or short backwash duration can reduce filter runs.	- See Item 2a.
	- Check air scour or surface wash (if applicable).	- Insufficient air scour or inoperable air wash can reduce filter runs.	- See Items 2b and 2c.
OPERATING PROBLEM 4: Filter effluent turbidity increases suddenly but filter headloss is low.			
4a. Inadequate dosage of polymers as filter aid.	- Run jar tests.	- Jar tests will indicate needed dosage of polymer.	- Adjust polymer dosage.
4b. Coagulant feed system malfunction.	- Check chemical feeders.	- Excessive turbidity can be caused by chemical feeder malfunction.	- Repair feeders.
4c. Change in influent characteristics.	- Check pH adjustment and clarification.	- Change in pH can change solubility and increase turbidity.	- See pH Adjustment Troubleshooting Guide and Sedimentation Troubleshooting Guide.
OPERATING PROBLEM 5: Mud ball formation.			
5a. Inadequate backwash or surface wash.	- Check backwash flowrate and duration.	- Backwash flowrate and duration may be too low.	- Provide backwash flow rate up to 20 gpm/sq.ft., and maintain proper auxiliary scour (surface wash).
5b. Media needs replacing.	- Look for cementaceous media.	- Cementaceous media will reduce filter run time.	- Replace media.

TABLE 17
(Continued)
FILTRATION TROUBLESHOOTING GUIDE
(GRANULAR DEEP BED FILTERS)

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 6: Loss of media during backwashing.			
6a. Excessive flows used for backwashing.	- Check backwash rate.	- High backwash can cause solids carryover.	- Reduce rate of backwash flow.
6b. Auxiliary scour excessive.	- Check backwash program.	- Excessive air scour can cause solids carryover.	- Cut off the auxiliary scour 2 min. before the end of the main backwash.
6c. Air bubbles attaching to anthracite causing it to float.	- Check for floating anthracite.	- Loss of anthracite can reduce effectiveness of filter system.	- Reduce air scour.

TABLE 17
(Continued)
FILTRATION TROUBLESHOOTING GUIDE
(PRESSURE FILTERS-CARTRIDGE)

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: High differential pressure across filter.			
1a. Cartridge plugged with solids.	- Filter cartridge.	- Plugged cartridge.	- Replace cartridge.
OPERATING PROBLEM 2: New cartridge but solids breaking through. Low differential pressure.			
2a. Defective "O" ring or cartridge seal.	- Cartridge seal.	- Solids could be bypassing cartridge.	- Replace seal.
2b. Hole in cartridge.	- Cartridge.	- Solids passing through hole.	- Replace cartridge.
OPERATING PROBLEM 3: Low differential pressure-solids passing through cartridge - no holes in cartridge - seals not defective.			
3a. Wrong cartridge.	- Cartridge type.	- Particles too small for cartridge.	- Change cartridge type.

represent the different types of filtration equipment. Each type of equipment is subject to its own kind of operating problems; most problems have to do with high head loss, short cycle times, backwashing problems, or inadequate solids capture.

SECTION 13

GRAVITY THICKENING

INTRODUCTION

Gravity thickening is a commonly used process for removing water from sludges generated during wastewater treatment, thereby concentrating them prior to dewatering or disposal. Sludges are thickened primarily to decrease the capital and operating costs of subsequent sludge processing steps by substantially reducing the volume. As shown in Figure 23, thickening from one to two percent solids concentration, for example, decreases the sludge volume by fifty percent. Further concentration to five percent solids reduces the volume to one-fifth of its original volume.

In plants in which thickening is the final treatment before sludge disposal, good operation of the gravity thickener can minimize final disposal costs by reducing the volume of sludge to be disposed. The degree of thickening can also affect the performance of downstream processes, particularly dewatering, since the efficiency of process equipment is often related to the concentration of solids in the feed sludge.

THEORY OF OPERATION

Gravity thickeners work on the principle that sludge solids are more dense than water and, under quiescent conditions, will settle and become concentrated over a period of time. As the sludge settles, it forms an interface with the clear water above. In a thickener the solids layer below this interface is referred to as the sludge blanket.

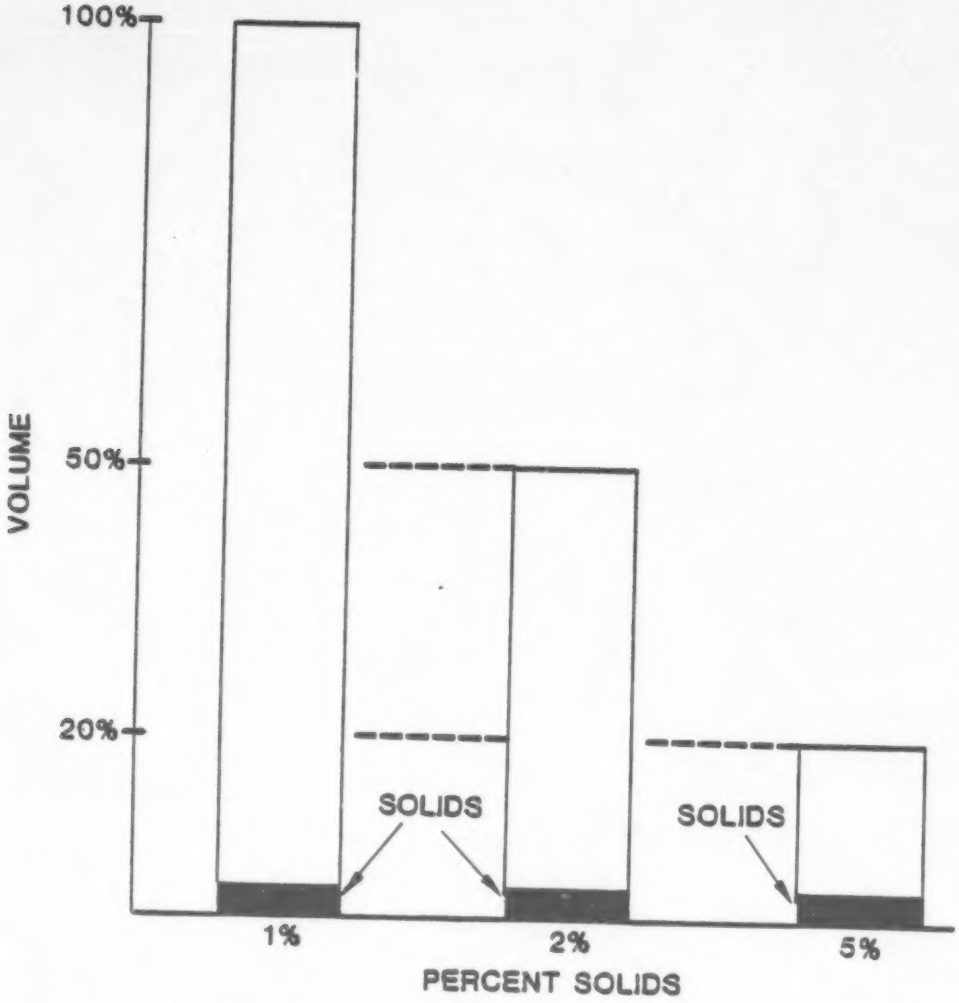

Figure 23. **Effect of gravity thickening upon solids concentration.**

Thickening, concentration, or compaction takes place in the sludge blanket as a result of compression caused by the weight of solids above and by the release of entrapped water. As the sludge becomes more concentrated, the interface moves downward. With time, the interface moves more and more slowly since it becomes progressively more difficult to compact solids and release water entrapped in the sludge. This compaction is illustrated in Figure 24.

Sludge is removed by pumping from the bottom of the thickener once the desired concentration has been achieved. The supernatant, or clear liquid, is usually sent back to an upstream treatment process since it is rarely of good enough quality to be discharged directly.

Often it is necessary to add chemical coagulants or settling aids to the sludge to improve its thickening characteristics and to maintain a clear supernatant. Polyelectrolytes are most commonly used for conditioning, although chemicals such as lime, alum, and ferric chloride are also used. The choices of conditioning agent(s) and optimum dosage rates are made experimentally in jar tests and through operating experience.

All gravity thickeners operate in one of two ways: either as a batch process or as a continuous process. In batch thickeners, sludge is pumped into the thickener and then sufficient time is provided for settling. Once the desired concentration is achieved, based upon either the sludge blanket (interface) level or the amount of time elapsed since batch thickening began, clear water is decanted off the top until only the sludge blanket remains. The sludge is then pumped to the next treatment process or to final disposal, making the thickener available for a new batch of sludge.

Continous thickeners operate much like clarifiers. Sludge enters at mid-depth, usually in a center well, and is removed by pumping from a hopper or collection box at the bottom. Sludge removal can be either continuous or intermittent with sludge pumps operating on a timed cycle. The latter mode of operation is more common. The supernatant or clear

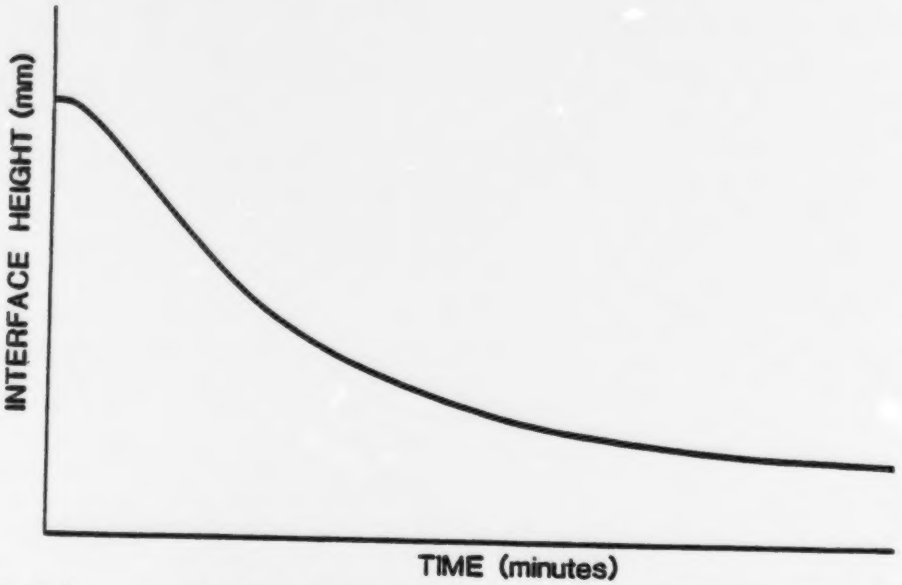

Figure 24. **Typical curve of effect of time on sludge compaction.**

liquid effluent continuously passes over weirs at the top of the thickener. The most basic difference between the two types of thickeners is in formation and behavior of the sludge blanket.

The concentration of solids within a continuously operated thickener is shown in Figure 25. There are three very distinct zones which develop in such a thickener. The clear zone on top is composed of liquid that eventually becomes the effluent or supernatant escaping over the weirs. This liquid has a very low solids concentration. The next zone is called the sedimentation zone; it is characterized by a fairly uniform solids concentration. Below the sedimentation zone is the thickening or compaction zone, characterized by an increasing solids concentration to the point of sludge discharge.

The sludge blanket in a continuous thickener is defined as beginning at the top of the sedimentation zone. Looking into an operating thickener, one can often see the sludge blanket below the clear effluent. The sludge blanket depth is the main operational control that a treatment plant operator has over a thickener. The blanket can be lowered by increasing the underflow sludge pumping rate (or reducing the cycle time on intermittent pumping systems) and blanket depth can be increased by decreasing the underflow rate.

DESCRIPTION OF EQUIPMENT

Most gravity thickeners are circular tanks, either concrete or steel, with sloped bottoms to help in moving the thickened sludge to a hopper or collection box from which it is removed by pumping. Sludge pumping is either continuous or on an intermittent cycle, depending upon the size of the unit. A rotating rake-arm equipped with scrapers is usually provided to push the sludge toward the center and into the hopper. Sometimes pickets are attached to the rake arm to gently agitate the thickened sludge and help release water entrapped in the sludge. Sludge enters the clarifier in a localized area that is enclosed by baffles to help maintain the quiescent conditions required for thickening. Relatively clear effluent passes over weirs at the top

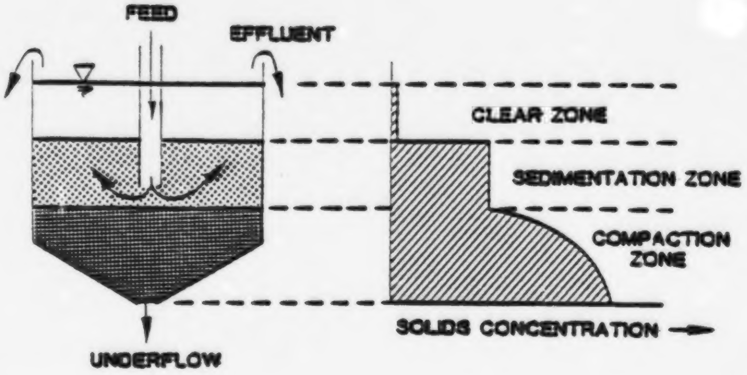
FEED
EFFLUENT
CLEAR ZONE
SEDIMENTATION ZONE
COMPACTION ZONE
SOLIDS CONCENTRATION →
UNDERFLOW

Figure 25. **Liquid zones in a continuously operated thickener.**

and usually is recycled back to a preceding treatment process. Some continuous thickeners are rectangular or even square basins, in which case they generally have moving flights to push sludge toward one end where it falls into a hopper or collection box and is removed by pumping.

Batch thickeners are similar to continuous thickeners except that they lack influent baffles and effluent weirs. Since sludge is added batchwise rather than continuously, influent baffles are not necessary in batch thickeners. Likewise, effluent weirs are not needed. Batch thickeners also have sloped bottoms and a rotating arm equipped with pickets and scrapers to help compact the sludge. The thickened sludge is pumped directly out of the bottom after the supernatant is decanted.

OPERATIONAL PROCEDURES

The main objective in operating thickeners is to provide the thickest possible sludge without upsetting the quality of the supernatant. This objective usually is accomplished by providing the maximum time possible for thickening to occur, or in other words, the longest possible solids residence time. In batch thickeners, one controls the settling time for each batch, taking into account the number of batches that must be thickened in a given period of time.

In continuous thickeners, control of the time available for thickening is usually achieved by adjusting the underflow pumping rate or cycle time to maintain a constant sludge blanket depth. Alternatively, the underflow rate can be controlled to maintain a constant solids concentration in the thickened sludge, which indirectly determines the average solids residence time within the thickener.

Process Monitoring

The main parameter used in evaluating thickener performance is the solids concentration in the thickened sludge.

Continuous gravity thickeners are usually designed to meet two conditions - maximum hydraulic overflow rate and a maximum solids loading. The overflow rate is generally expressed as a surface loading rate with units of gallons per day per square foot of thickener surface area (gal/ft^2/day). A maximum overflow rate is established to insure that adequate residence time is provided for a sludge blanket to form and for solids separation or clarification to occur. Otherwise, the supernatant would contain an unacceptably high solids concentration. The maximum solids loading rate is determined by how well the sludge compacts, and is established to insure adequate time for solids thickening or compaction to occur in the sludge blanket layer. The solids loading is also expressed as a surface loading, with units of pounds of solids per square foot of surface per day (lb/ft^2/day).

The operation of gravity thickeners is fairly simple, provided the operator has sufficient data to allow a determination of the cause of problems when they occur. Even small changes in sludge characteristics, temperature, pH, flow rates, or other factors can reduce thickener performance. To determine the cause of a problem, a complete record of operating data is necessary. With such information, the operator can compare periods of good and poor thickener performance and easily identify changes in operating conditions which may be causing poor thickening. The data which should be monitored routinely are presented in Table 18.

In addition to the data collected above, several calculated parameters can be used to characterize and monitor thickener performance. Among these are sludge volume ratio, solids loading rate, surface overflow rate, and sludge wasting rate.

The sludge volume ratio (SVR) is an estimate of the average solids residence time or thickening time provided in a continuous thickener. It is calculated by dividing the sludge blanket volume by the underflow pumping rate and is usually expressed in units of hours or days.

TABLE 18

GRAVITY THICKENING
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Influent suspended solids concentration (mg/L).	Daily	To determine solids loading and removal efficiency.
2. Underflow suspended solids concentration (mg/L).	Daily	To calculate solids loading to downstream treatment processes.
3. Sludge blanket depth (ft or meters).	Daily	To determine whether sludge is accumulating in clarifier.
4. Effluent or supernatant suspended solids concentration (mg/L).	Daily	To determine removal efficiency.
5. Chemical dosage rate (ppm or mg/L).	Daily	To adjust/optimize chemical dosage as necessary.
6. Influent flow rate (m^3/min or gpd).	Continuously	To calculate solids loading.
7. Underflow pumping rate (gpm or m^3/min).	Daily	To determine sludge loading to downstream treatment processes.

The solids loading rate is the mass of suspended solids applied to the thickener each day divided by the thickener surface area. It has the units of lb/ft^2 day or kg/m^2 day.

The surface overflow rate is the total volume of water passing over the effluent weirs in a day divided by the thickener surface area. It is expressed in units of gal/ft^2 day or L/m^2 day.

The sludge wasting rate refers to the mass of suspended solids removed in the underflow each day, expressed on a dry weight basis. It is calculated by multiplying the average underflow pumping rate by the underflow suspended solids concentration and has units of lb/day or kg/day.

Example Calculations

The following examples show how the various operating parameters are calculated. Consider a gravity thickener for which the following data have been collected.

(1) Thickener diameter = 20 feet

(2) Average sludge blanket depth = 8 feet

(3) Underflow sludge pumping is intermittent. Pumps are on for 10 minutes every half hour and pump at a rate of 15 gallons per minute.

(4) Influent flow rate = 25 gpm

(5) Influent suspended solids (TSS) concentration = 15,000 mg/L

(6) Average underflow pumping rate = 5 gpm

(7) Underflow suspended solids concentration = 72,000 mg/L

Sludge Volume Ratio--

Thickener Surface Area = (Diameter/2)^2(3.14) = 314 square feet

Sludge Blanket Volume = (Thickener Surface Area)(Blanket Depth) = (314 square feet)(8 feet) = 2,512 cubic feet in blanket

Conversion From Cubic Feet to Gallons = 7.48 gallons/cubic foot

(2,512 cubic feet)(7.48) = 18,792 gallons in blanket

Average Underflow Pumping Rate = (Pumping Rate)(Pumping Time)/(Cycle Time) = (15 gpm)(10 minutes)/(30 minutes) = 5 gpm

SVR = (Sludge Blanket Volume)/(Average Underflow Pumping Rate) = (18,792 gallons)/(5 gpm) = 3,758 minutes

(3,758 minutes)(1,440 minutes per day) = 2.61 days

Solids Loading Rate--

Thickener Surface Area = (Diameter/2)^2(3.14) = 314 square feet

Daily Flow = (25 gallons/minute)(1,440 minutes/day) = 36,000 gpd

(36,000 gpd)/(1,000,000) = 0.036 Mgd

Mass of Influent Solids per Day = (Infl. Flow)(Infl. TSS)(8.34) = (0.036 Mgd)(15,000 mg/L)(8.34) = 4,504 lb solids per day

Solids Loading Rate = (Mass of Influent Solids/Day)/(Thickener Surface Area) = (4,504 lbs solids per day)/(314 sq ft) = 14.3 lb/sq ft day

Surface Overflow Rate--

Daily Effluent Flow = (Influent Flow Rate)-(Average Underflow Pumping Rate) = (25 gpm) - (5 gpm) = 20 gpm

(20 gpm)(1,440 minutes per day) = 28,800 gpd

Surface Overflow Rate = (Daily Effluent Flow)/(Thickener Surface Area) = (28,800 gpd)/(314 square feet) = 92 gal/sq ft/day

Sludge Wasting Rate--

Daily Volume of Sludge Underflow = (5 gpm)(1,440) = 7,200 gpd

(7,200 gpd)/(1,000,000) = 0.0072 Mgd

Sludge Wasting Rate = (Daily Underflow Volume)(Underflow Solids Concentration)(8.34) = (0.0072 Mgd)(72,000 mg/L)(8.34) = 4,323 lb solids per day

For the influent mass of solids = 4,504 lb/day,

(4,323)/(4,504) x 100 = 96.0 % of solids are in underflow

Process Control Strategies

The simplest type of thickener to operate is a batch thickener since the only operational control is the amount of time provided before decanting off the clear liquid. The optimum time must be determined from operating experience and will depend upon the desired underflow solids concentration and the total amount of sludge that must be thickened in a given period of time with the available equipment.

In a continuous gravity thickener, the depth of the sludge blanket (or position of the sludge-liquid interface) is the main process variable used for control. The sludge blanket can be lowered by increasing the underflow sludge pumping rate (or reducing the cycle time on intermittent pumping systems) and can be raised by decreasing the underflow rate. Lowering the sludge blanket essentially reduces the average solids residence time within the thickener and, as is the case in batch thickeners, this usually results in a lower solids concentration in the underflow. Increasing the sludge blanket depth results in a longer solids residence time which usually results in a higher underflow solids concentration.

One advantage of maintaining a lower sludge blanket is that some extra sludge storage capacity is provided within the thickener for periods of high sludge loadings or for occasions when downstream equipment is being serviced or repaired.

Sometimes thickeners are operated to maintain a minimum sludge volume ratio (SVR). While the SVR is helpful in understanding the operation of a thickener, its use as an operational control parameter is limited unless the underflow solids concentration and other factors are also considered. For example, the SVR could increase while at the same time the underflow solids concentration drops, if the influent solids concentration decreases or if a problem occurs with the operation of the chemical addition system.

Solids loading and solids wasting rates are useful in several ways. The solids wasted each day should be almost the same as the solids fed to the thickener. If not, one of three things must be happening. Either solids are accumulating in the sludge blanket, solids are being lost from the sludge blanket, or solids are leaving the thickener with the effluent. On a short-term basis, only the last of these possibilities is really to be avoided, since a high solids concentration in the supernatant defeats the purpose of thickening and can cause problems in other treatment processes. Over a longer period of time changes in the sludge blanket can also cause problems. As discussed earlier, there are limits to the range in which the sludge blanket can be maintained without reducing underflow solids concentration too much or increasing solids to the point that underflow pumping becomes difficult.

TYPICAL PERFORMANCE VALUES

Performance of gravity thickeners can vary considerably depending upon design features such as solids loading and surface overflow rates. Another factor affecting performance is the nature of the sludge. Metal hydroxide sludges are lighter and do not thicken as well as lime sludges that are high in calcium carbonate concentration. A gravity thickener is designed to achieve about 95 percent solids capture and will produce a thickened sludge ranging from 4 to 10 percent solids. Sludges much thicker than 10 percent may be achievable, but are often difficult to pump and handle. As a minimum, the thickener should about double the solids concentration of the sludge.

TROUBLESHOOTING GUIDE

The problems which are commonly associated with gravity thickener operation have been summarized in the form of a troubleshooting guide in Table 19. Specific details on pumps, sludge rake drives, and other

TABLE 19
GRAVITY THICKENING TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Thickened sludge is too thin.			
1a. Underflow pumping rate is too great.	- Blanket depth and pumping rate.	- Low blanket indicates pumping rate is too high, may be confirmed if pumping rate has been increased recently.	- Decrease pumping of thickened sludge to maintain a blanket volume between 1/4 and 1/2 of total thickener volume.
1b. Surface overflow rate is too great in continuous thickener.	- Check for high solids in effluent and increased feed flow rate.	- Increased overflow rate results from higher flows and usually results in greater solids losses in the effluent.	- Reduce flow to thickener if possible to keep a maximum surface overflow rate of 600-800 gpd/ft^2. (See also Items 1e and 3a).
1c. Insufficient time for settling in batch thickeners.	- Check the time allowed for settling against previous data and perform batch settling tests.	- To determine if sufficient time is being provided for settling and if sludge characteristics have changed.	- If necessary and possible, allow more time per batch for settling and thickening to occur.
1d. Short-circuiting of flow through thickener.	- Check for high effluent solids concentrations. Inspect surface of clarifier for evidence of uneven flow and solids discharge. Check level of weirs.	- Short circuiting reduces the time available for settling and results in higher effluent solids.	- Level weirs and repair or adjust influent baffles to eliminate short circuiting.
1e. Improper chemical dosage or wrong chemical being used.	- Check chemical addition system for malfunction and check chemical flow.	- Problem may be equipment malfunction or improper setting. If neither, the dosage or chemical used must be changed.	- Repair, replace, or adjust equipment if this is the problem. Otherwise, perform jar tests to select new chemical and/or dosage rates to be used.
1f. Sludge collection or conveying equipment not functioning properly.	- Check for non-uniform blanket and rat-holing (coning). Check to see that drive is working properly. Use probe to check for broken rake or pickets.	- Sludge may be accumulating elsewhere in thickener than the sludge hopper or broken rakes and pickets may cause water to be entrapped in thickened sludge.	- Repair or replace broken equipment, drain tank if necessary.

TABLE 19
(Continued)
GRAVITY THICKENING TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 2: Torque overload on sludge collection equipment.			
2a. Heavy accumulation of sludge in bottom of thickener - sludge too thick.	- Check sludge blanket depth and underflow solids concentration.	- Sludge can get too thick to move, especially if blanket is very thick.	- Agitate sludge in front of collection equipment using rod, water jet, or air.
2b. Foreign object jamming equipment.	- Inspect all visible parts for foreign objects. Probe along front of underwater collection equipment.	- To determine the presence and location of foreign objects.	- Remove foreign object. Use grappling hook, if possible, for objects underwater. Drain tank if necessary.
2c. Mechanical problems such as insufficient lubrication.	- Check maintenance records, lubricant reservoirs, and free movement of parts.	- Poor maintenance, such as improper lubrication, can cause friction that increases torque.	- Correct any problems and revise routine maintenance procedures to to prevent future problems.
OPERATING PROBLEM 3: Plugging of sludge pumps or pipelines.			
3a. Underflow sludge concentration too high due to insufficient pumping.	- Check blanket level and underflow solids concentration.	- Sludge can become too thick to pump.	- Flush out plugged lines with water, making sure all valves are open. If this doesn't work, try 2a above. Increase underflow pumping rate or decrease pump cycle time to reduce blanket level and underflow solids concentration.
OPERATING PROBLEM 4: Poor solids capture.			
4a. Overflow rate too high.	- See Item 1b.	- See Item 1b.	- See Item 1b.
4b. Short circuiting of flow through thickener.	- See Item 1d.	- See Item 1d.	- See Item 1d.

TABLE 19
(Continued)
GRAVITY THICKENING TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
4c. Improper chemical dosage or wrong chemical.	- See Item 1e.	- See Item 1e.	- See Item 1e.
4d. Excessively high sludge blanket due to insufficient underflow pumping rate.	- Check blanket level and underflow pumping rate.	- A high sludge blanket can cause carryover of solids in effluent.	- Increase underflow pumping to reduce blanket level to half or less of total thickener volume.
OPERATING PROBLEM 5: Changing sludge blanket level at constant underflow pumping rate.			
5a. Changing influent flow rates or solids loadings.	- Influent, effluent, and underflow rates and solids concentrations.	- To isolate the causes of the fluctuations and determine how rapidly they occur.	- If underflow solids concentration and effluent quality are acceptable, do nothing. If either is inadequate, make adjustments in underflow rate to achieve an acceptable average condition or, if possible, even out flow rate to thickener.

equipment can be found in the manufacturer's literature. The two predominant problems considered in Table 19 are inadequate thickening of the sludge and problems with sludge blanket level.

SECTION 14

BELT FILTER PRESSES

INTRODUCTION

The treatment of metal plating wastewater often generates dilute sludges during treatment processes such as metal precipitation. These sludges are difficult to dispose of because of their volume and their liquid nature. It is therefore advantageous to dewater the sludges. Dewatering reduces volume and weight of sludges and allows them to be handled as solids.

A belt filter press is a device for accomplishing sludge dewatering. The process produces a solids cake and a relatively clean water stream called the filtrate. Often belt filter presses used for dewatering are preceded by a gravity thickener or centrifuge to increase the solids concentration of the sludge fed to the filter. This combination helps to maximize the solids content of the cake produced.

THEORY OF OPERATION

Filtration for dewatering is a process whereby solids are separated from a liquid by passing the liquid through a porous medium on which the solids remain, eventually building up to form a cake that is removed for disposal. The formation of a solids cake and the fact that solids are removed primarily on the surface of the medium rather than throughout its depth are two distinguishing features that characterize this type of filtration. Both features are important since the object of dewatering is to maximize the recovery of solids in a concentrated form.

DESCRIPTION OF EQUIPMENT

The belt filtration process includes three basic operational stages: chemical conditioning of the feed slurry, gravity drainage to a nonfluid consistency, and compaction of the previously dewatered sludge. These stages are shown in the simple belt filter press shown in in Figure 26. Although present-day belt presses are more complex, they follow the same principles indicated in Figure 26.

Chemical conditioning is essential for successful and consistent performance of the belt filter press, as for other dewatering processes. As shown in Figure 26, a flocculant (usually an organic polymer) is added to the sludge prior to the sludge being fed to the belt press. Free water then drains from the conditioned sludge in the gravity drainage stage of the press.

Following gravity drainage the sludge enters a contact zone usually consisting of two belts. The sludge is initially gently pressed between the two belts and carried towards a series of rollers with generally decreasing diameters. This stage subjects the sludge to continuously increasing pressure and shear forces. Progressively, more and more water is expelled throughout the roller section to the end where the cake is discharged. A scraper blade is often employed for each belt at the discharge point to remove the cake from the belts.

After scraping the cake from the belts, the belts are subjected to a spray wash to clean any remaining solids from the belt surface. Usually treated wastewater is used as a water source. The spray water is then combined with the filtrate and returned to the influent of the treatment plant.

OPERATIONAL PROCEDURES

The objective of operating a belt filter press is to concentrate sludges into a dry cake suitable for disposal. The filter press also produces a filtrate that must be maintained relatively free of solids.

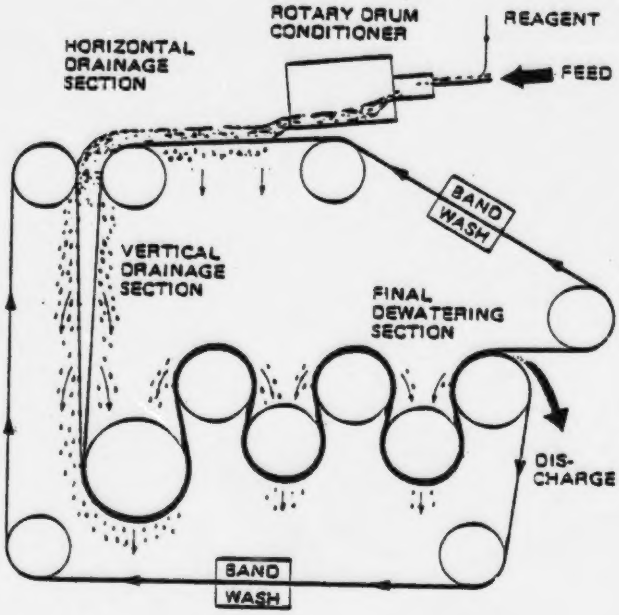
ROTARY DRUM CONDITIONER
REAGENT
HORIZONTAL DRAINAGE SECTION
FEED
BAND WASH
VERTICAL DRAINAGE SECTION
FINAL DEWATERING SECTION
DIS-CHARGE
BAND WASH

Figure 26. **A simple belt filter press.**

Excessive solids in the filtrate will get recycled through the treatment process and may adversely affect other treatment operations.

Process Monitoring

The primary criteria for evaluating the performance of a belt filter press are percent solids in the filter cake and the percentage of total solids entering the filter press that are captured in the cake. The calculation of these parameters and other parameters necessary for successfully operating a filter press are listed in Table 20.

The above parameters, with the possible exception of filtrate flow rate and total dissolved solids concentration, should be measured any time the belt press is used. Filtrate flow rate and total dissolved solids concentration may be measured less frequently but still should be measured approximately monthly. In addition the belt speed and the type and application rate of chemical conditioner should be recorded.

Example Calculations

Influent Suspended Solids--

Influent suspended solids are often difficult to measure directly in thick sludges. Therefore this parameter is often calculated by measuring the total solids in the influent and subtracting the filtrate total dissolved solids. If possible the filtrate total dissolved solids sample should be collected prior to the addition of wash water.

Percent Capture--

Percent capture is the percentage of influent solids that are captured in the cake. Percent capture is calculated as follows:

$$\% \text{ Capture} = 100 \times \left(1 - \frac{\text{Filtrate SS} \times \text{Filtrate Flow}}{\text{Influent SS} \times \text{Influent Flow}}\right)$$

An alternate, but less sensitive technique, for calculating percent capture is available when details about the filtrate are unavailable:

TABLE 20

BELT FILTER PRESS
PROCESS MONITORING REQUIREMENTS

	Parameter	Frequency	Comment
1.	Influent flow rate (gpm or L/min).	Continuously	- To set chemical dosages and to set flow rate.
2.	Filtrate flow rate (gpm or L/min).	Monthly	- To determine mass (solids) loading of filtrate.
3.	Influent total solids concentration (mg/L).	Daily	- To set chemical dosage and to set flow rate.
4.	Filtrate suspended solids concentration (mg/L).	Monthly	- To determine mass (solids) loading of filtrate.
5.	Percent solids in cake.	Weekly	- To determine percent capture.
6.	Net cake production rate (lb/hr, kg/hr, yd^3/hr, or m^3/hr).	Weekly	- To set loading rate.
7.	pH	Continuously	- High or low pH values can increase solubility of particles.
8.	Chemical conditioner type and concentration.	Weekly	- To set chemical dosage.

$$\text{\% Capture} = \frac{\text{Wet Cake Production Rate x Percent Cake Solids}}{\text{Influent SS x Influent Flow}}$$

When using the above equations care must be taken to convert all parameters to similar units.

As an example, if a belt filter press received 50 liters/min of 20,000 mg/L sludge and produced 190 kg/hour of 30% cake the percent capture would be:

$$\text{\% Capture} = \frac{190 \text{ kg/hr} \times (1{,}000{,}000 \text{ mg/kg}) \times (\text{hr}/60 \text{ min}) \times 30}{20{,}000 \text{ mg/L} \times 50 \text{ l/min}} = 95$$

Conditioning Agent Application Rate--

As previously described, the pretreatment of the sludge with chemical conditioning agents is essential for good dewatering. Typically, the conditioning agent is a polymer which is purchased in a dry or liquid form. The polymer is then diluted with water to a concentration that typically ranges from 1000 to 5000 mg/L (0.1 to 0.5 percent). The operator is advised to see manufacturer's recommendations for concentrations. This dilute polymer solution is then applied to the sludge on a basis of mass of polymer to mass of sludge suspended solids. The application rate of conditioner can be calculated as follows:

$$\text{Feed Rate} = \frac{\text{Polymer Dosage x Influent Flow x Influent SS}}{\text{Polymer Solution Concentration}}$$

where polymer dosage is the ratio of the weight of polymer applied per weight of influent solids and feed rate is the polymer pumping rate.

As an example, suppose a sludge stream containing 20,000 mg/L (2.0 percent) solids is being dewatered using a belt filter press at a rate of 50 liters per minute. Jar testing has indicated that a polymer dosage rate of five pounds of polymer per ton of dry solids is the optimum dosage rate and the manufacturer recommends that the polymer be diluted and premixed with water to a concentration of 5000 mg/L (0.5% solution). The polymer feed rate could then be calculated as follows:

$$\text{Feed Rate} = \frac{\dfrac{5 \text{ lb}}{\text{ton}} \times \dfrac{\text{ton}}{2000 \text{ lb}} \times \dfrac{50 \ \ell}{\text{min}} \times \dfrac{20{,}000 \text{ mg}}{\text{L}}}{5000 \ \text{mg/L}} = 0.5 \text{ L/min}$$

One must use extreme care to make sure that the proper units and conversion factors are used.

Process Control Strategies

The operator of a belt filter press has several operating variables that are under his direct control. These variables and their effect on dewatering are listed below.

Sludge Feed Rate--

Increasing sludge feed rate will increase machine throughput if the belt speed is high enough, but will also cause an increase in cake moisture.

Conditioning Agent--

Proper selection of conditioning agent can dramatically increase solids capture and percentage of solids in cake. Selection of polymer is usually made based on jar test results.

Conditioning Agent Application Rate--

As polymer dosages increase, both cake solids and solids capture increase until an upper limit is reached. If sludge is underconditioned, improper drainage occurs in the gravity drainage section, and either extrusion of inadequately drained solids from the compression section or uncontrolled overflow of sludge from the drainage section may occur. Most belt presses can be equipped with sensing devices which can be set to automatically shut off the sludge feed flow in case of underconditioning. Both underconditioned and overconditioned sludges can blind the filter media. In addition, overconditioned sludge drains so rapidly that solids cannot distribute across the belt. Vanes and distribution weirs included in the gravity drainage section help alleviate the problem of distribution of overconditioned sludge across the belt. Inclusion of a sludge blending tank before the belt press can also reduce this problem.

Belt Speed--

Increasing belt speed can increase machine throughput but will typically result in lower cake solids content because both gravity drainage time and press time are decreased. Conversely, decreasing belt speed should result in a drier cake.

Belt Tension--

Increasing belt tension will promote a drier cake but solids capture typically will decrease and belt wear will increase.

Washwater Flow Rate--

An increase in washwater flow and/or pressure can increase cake solids concentration if the washwater was not adequately cleaning the belt, but also increases the flow requiring retreatment back to the head end of the plant. The flow rate required for belt washing is usually 50 to 100 percent of the flow rate of sludge to the machine and the pressure is typically 690 kPa (100 psi) or more. The combined filtrate and belt washwater flow is normally about 1.5 times the incoming sludge flow.

Belt Material--

Belts with different pore sizes are available. Increasing the porosity will increase the solids content of the cake, but will decrease the percent capture.

pH--

The pH of the sludge usually has little effect on polymers. The pH can, however, significantly affect the sludge material. Most sludges are metal precipitates and changing the pH can resolubilize a significant fraction of the sludge. This resolubilization is most likely to happen if sludges from two separate precipitations at different pH levels were mixed.

Polymer Addition Point--

It is essential that the polymer and sludge be properly mixed. Mixing usually occurs in a small tank prior to the belt filter press.

However, in some systems polymer is injected to the feed pipe to the filter press. Changing the injection point can significantly change the effectiveness of the polymer. Typically, increasing the distance between the injection point and the press will improve performance.

Influent Solids Concentration--

In general, a thicker incoming sludge will produce a drier cake. However, the initial solids concentration is not normally a process control variable. It is customary, unless special conditions apply, to deliver as thick a sludge as practical to the belt filtration unit.

TYPICAL PERFORMANCE VALUES

The performance of a properly operated belt filter press will vary significantly depending primarily upon the material being dewatered. Metal carbonates, such as those generated during lime precipitation, dewater easily with cake solids concentration in the range of 35 to 45% and capture ratios of over 95%. Hydroxide sludges usually do not dewater as well as carbonates. Typical cake solids concentrations will be 20 to 30% with capture ratios of 90 to 95%.

TROUBLESHOOTING GUIDE

The troubleshooting guide for the belt filter press process is presented in Table 21. The major problem in belt filter press operation is too thin or watery a sludge cake. The corrective methods involve either mechanical corrections (belt speed, application rate, etc.) or chemical changes (adjustments to the flocculation process, etc.). The problem of excessive belt wear is also addressed is Table 21.

TABLE 21
BELT FILTER PRESS
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Dewatered sludge not thick enough.			
1a. Sludge application rate too high.	- Check sludge pumping rate.	- Excessive pumping causes excessively thick cake that does not have time to dewater.	- Adjust influent sludge pumping rate.
1b. Belt speed too high.	- Check belt speed.	- Sludge is carried through belt press before it has time to dry.	- Adjust belt speed.
1c. Incorrect polymer dose.	- Check polymer type, initial dilution, and flow rate. Determine polymer application rate on a pound polymer to ton of dry solids basis.	- Proper polymer dosage is essential for effective dewatering.	- If polymer dose is much less or much greater than optimum dose, performance will decrease. Use jar test procedure to determine optimum dose.
1d. Poor polymer-sludge mixing	- Check polymer-sludge mixing.	- Improper mixing of polymer and sludge can completely negate the benefits of polymers.	- Enhance mixing. Change polymer addition point.
1e. Belt tension inadequate.	- Check belt tension.	- Insufficient tension will not force water out of cake.	- Increase belt tension.
1f. Improper belt type.	- Check belt type and manufacturer's recommendations.	- Belt porosity can directly affect cake solids content.	- Change belt.
1g. Insufficient wash water or pressure.	- Check belt to see if it is clean after washing.	- A dirty belt can inhibit the transport of water through the belt during dewatering.	- Increase water pressure and/or flow.

TABLE 21
(Continued)
BELT FILTER PRESS
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 2: Excessive belt wear.			
2a. Improper alignment of rollers.	- Check tracking of belt to see if it creeps off to one side.	- Can cause excessive pressure on localized areas.	- Adjust alignment of belt.
2b. Sludge buildup on bottom of belt or on rollers causing improper alignment.	- Check bottom of belt and the rollers.	- Can cause excessive pressure on localized areas.	- Clean belt and rollers.
2c. Belt tension too high.	- Check belt tension and automatic tension adjustment mechanism.	- Excessive tension causes wear.	- Adjust tension; repair tension adjustment equipment.

SECTION 15

VACUUM FILTRATION

INTRODUCTION

Vacuum filtration is a process used for dewatering sludges generated during wastewater treatment. The two products of vacuum filtration are a relatively clear liquid, the filtrate, and a solids cake which is suitable for final disposal. Depending upon the type of sludge being dewatered, vacuum filtration can produce a cake that is typically between 20 and 30 percent solids. Often, vacuum filters used for dewatering are preceded by a gravity thickener or a centrifuge to increase the solids concentration of the sludge fed to the filter, a combination which helps to maximize the solids content of the cake produced.

THEORY OF OPERATION

Filtration for dewatering is a process whereby solids are separated from a liquid by passing the liquid through a porous medium on which the solids remain and eventually build up to form a cake that is removed for disposal. The formation of a solids cake and the fact that solids are removed primarily on the surface of the medium rather than throughout its depth are two distinguishing features that characterize this type of filtration. Both features are important since the object of dewatering is to maximize the recovery of solids in a concentrated form.

Two steps are involved in the vacuum filtration process. In the first, a solids cake is formed when a portion of the water in the sludge drains through the filter medium leaving a more concentrated but still very wet sludge layer or cake behind. In the second step, additional water drains from the solids, resulting in a much drier cake that can be handled as a solid material and is suitable for disposal. Thus, filtration to form a dry solids cake works on the same basic priniciple as do sludge drying beds, which are sometimes used for dewatering of metal finishing sludges.

The rate at which a solids cake is formed and is dried depends upon the rate at which water drains through the filter medium. In sludge drying beds, gravity is the force which causes the water to drain out of the sludge solids (the importance of evaporation is neglected in this discussion). To increase the rate at which sludge can be dewatered and thereby reduce the land area or size of equipment required, vacuum filters were developed. Such machines apply a suction or vacuum to one side of the filter medium while liquid sludge is applied to the other. Water is removed by the force of the pressure differential that develops across the medium, a pressure differential which is much greater than the force exerted by gravity.

Many types of vacuum filters and filter media have been developed, and several have been successfully used for dewatering sludges generated during treatment of metal finishing wastes. All operate on the same basic principle, differing primarily in the means by which the sludge is applied to and the solids cake removed from the medium. Although the process itself is fairly simple, the complexity of both machine-related and process- or sludge- related variables makes the operation of vacuum filters as much of an art as a science. For example, to optimize filter performance often requires that sludge conditioning with polymers and other chemicals be used. Although jar tests can be used to select appropriate polymers, finding the best combinations and optimum dosages is largely a matter of operating experience.

DESCRIPTION OF EQUIPMENT

Almost all of the vacuum filters used in wastewater treatment applications operate continuously and have as their principal component a horizontal cylindrical drum which rotates partially submerged in a vat or tank containing the sludge to be dewatered, as shown in Figure 27. The drum is divided by partitions or seal strips into multiple compartments or sections each of which is connected by pipe to a rotary valve within the drum. Bridge blocks in this valve divide the drum compartments into three zones referred to as the cake formation zone, the cake drying zone, and the cake discharge zone.

The portion of the drum which is submerged in the sludge vat is the cake formation zone. Vacuum applied through the rotary valve to this portion of the drum causes liquid (filtrate) to pass through the medium with the sludge being retained on its surface in the form of a wet cake. The sludge vat is usually equipped with a reciprocating agitator to keep the slurry mixed and solids in suspension. As the drum rotates, each section or compartment is passed through the cake formation zone and on to the cake drying zone. Beginning where the rotating drum leaves the vat of liquid sludge, the cake drying zone usually represents 40 to 60 percent of the drum surface and ends at the point where the internal vacuum is shut off by the rotary valve. Here the sludge cake and drum section enter the cake discharge zone where the cake is removed from the medium.

A few vacuum filters have a gravity feed system which applies sludge directly on the top of the drum for cake formation rather than having the drum pass through a vat of sludge. Otherwise, the operation of this type of filter is essentially the same as the others.

The cake discharge cycle depends upon the type of filter medium used. The earliest type developed employs a scraper mechanism and a pressure blow-back system for cake removal. A positive air pressure is continuously applied through the rotary valve to the drum segment just preceding the scraper or "doctor" blade; the air aids in loosening the dried cake for removal. Often a fine spray is used to clean the medium after cake removal, with the washings being captured in a trough for recycle to a preceding treatment process.

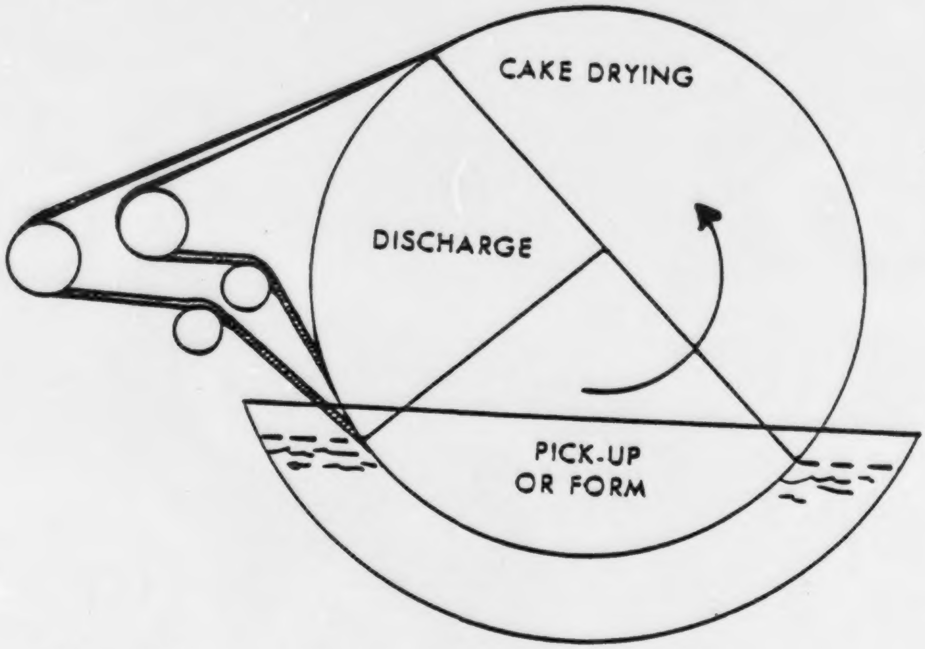
CAKE DRYING
DISCHARGE
PICK-UP
OR FORM

Figure 27. Operating zones of a vacuum filter.

More recently the belt-type rotary vacuum filters have gained in popularity since they do not depend upon intimate contact between a scraper and the rotating drum for effective removal of the solids cake. Rather, the filter medium forms a continuous belt that leaves the rotating drum when it enters the cake discharge zone and returns just before the cake formation zone. This kind of filter is shown in Figure 27. Three types of media or drum coverings have been used commonly: coil springs, closely spaced strings, and either woven cloth or metal fabric.

In one type of coil spring, belt-type vacuum filter, two layers of stainless steel springs wrap around the drum and act as the filter medium. After leaving the cake drying zone, the coil springs leave the drum and are separated in such a manner that the sludge cake is lifted off the lower layer and discharged off the upper layer with the aid of a positioned tine bar. The two coil spring layers are then washed with a water spray before returning to the drum just ahead of the cake formation zone.

A very similar type of filter uses closely spaced strings which are wrapped around the filter drum and serve as the medium. After leaving the drum, the strings pass over a series of discharge and return rolls which frees the cake from the medium. The strings then pass through a set of aligning combs before returning to the drum.

The other type of rotary vacuum belt filter has a fiber belt made of woven cloth (either natural or synthetic) or metal. A wide range of materials has been developed for use as filter media and the selection of media type and pore size for use with a particular sludge is a critical variable affecting filter performance. In this type of filter, the belt (or filter medium) leaves the cake drying zone and passes over a small diameter discharge roll which facilitates cake removal. Generally this type of filter has a small diameter curved bar between the point where the belt leaves the rotating drum and the discharge roll. The position of this bar can be adjusted so that it pushes against the inside of the belt to control belt tension and maintain dimensional stability. After the cake is discharged, the belt usually is washed with water sprays from one or both sides before it returns to the drum just ahead of the cake formation zone.

There are several important auxiliary equipment items which are part of the vacuum filtration system. These are vacuum pumps, vacuum receiver, filtrate pump, sludge pump, chemical feed system, sludge conditioning tank, silencer, and, with some units, blowers. In larger facilities these auxiliary items are often remote from the filters themselves and several filters may be served by the same equipment through common headers. A schematic illustration of a typical system is presented in Figure 28.

The most important auxiliary item is, of course, the vacuum pump which provides the negative pressure filtering force. Several types of vacuum pumps have been used including reciprocating positive displacement types, centrifugal (wet), and rotary or lobe pumps (semi-wet). Depending on solids content and chemical composition, the filtrate is sometimes used as seal water on these pumps. A silencer usually is provided on the discharge of a vacuum pump to reduce the noise produced during its operation. The "wet" operating pumps must also have provisions for water separation and draining of the seal water. Vacuum pumps are usually sized to provide between 1 and 2 scfm/sq ft of filter surface area at negative operating pressures of 20 inches of mercury.

Each filter generally is supplied with a vacuum receiver located between the rotary valve (which distributes the vacuum inside the drum) and the vacuum pump. The principal purpose of the vacuum receiver is to separate the air from the filtrate, as well as to serve as a reservoir for the filtrate pump suction. With dry-type vacuum pumps, a moisture trap is provided between the vacuum receiver and the pump.

Usually a filtrate pump is provided to carry away the water separated in the vacuum receiver. Specially designed centrifugal pumps that operate at very low net positive suction heads are used for this purpose, since the receiver is often under a negative pressure of about 20 inches of mercury. Check valves generally are provided on the discharge

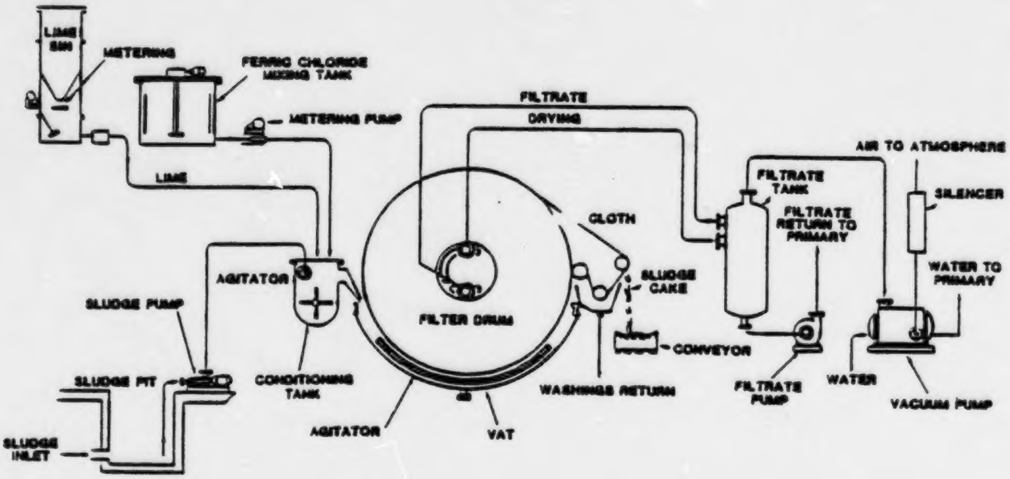
LIME BIN
METERING
FERRIC CHLORIDE MIXING TANK
METERING PUMP
FILTRATE
DRYING
AIR TO ATMOSPHERE
LIME
FILTRATE TANK
SILENCER
CLOTH
FILTRATE RETURN TO PRIMARY
AGITATOR
SLUDGE CAKE
WATER TO PRIMARY
SLUDGE PUMP
FILTER DRUM
CONVEYOR
SLUDGE PIT
CONDITIONING TANK
WASHINGS RETURN
FILTRATE PUMP
WATER
VACUUM PUMP
AGITATOR
VAT
SLUDGE INLET

Figure 28. **Typical equipment layout of rotary vacuum filter system.**

side of these pumps to prevent air from leaking back through the pump and into the receiver. Sometimes the filtrate pump is omitted when a barometric leg or gravity discharge is provided on the bottom of the receiver.

Piston, diaphragm, and progressive cavity pumps are all commonly used as sludge feed pumps. They are installed so that a constant capacity can be maintained at a given setting. Usually a stroke counter or other totalizing device is provided for flow measurement.

A sludge conditioning tank usually is provided in close proximity to the vacuum filter from which the conditioned sludge either flows by gravity or is pumped to the filter. The tank acts as both a mixing vessel and a flocculation tank. Other aspects of the chemical addition system are common to other sludge handling systems and are described in a separate section.

In vacuum filters that have a positive pressure blow-back system to lift the medium from the filter drum ahead of a scraper or doctor blade, low capacity lobe type air blowers are used. These are usually sized to provide about 0.25 scfm/sq ft of filter surface area and operate at pressures of about 2 psig.

OPERATIONAL PROCEDURES

The main objective of vacuum filter operation is to produce a sludge cake with a high solids concentration (low moisture content) that is suitable for final disposal. In doing so, the filtrate that is produced must be low in suspended solids so that problems are not created when it is recycled back to preceding treatment processes. Further, these two objectives must be met without reducing the filter yield below a level sufficient to handle the sludge solids generated during wastewater treatment. Otherwise, solids will accumulate in the system and will eventually affect other treatment processes. Maintaining an acceptable filter yield often requires the addition of chemical coagulants and filter aids. Another process objective is to minimize the operating costs associated with sludge conditioning. Vacuum filter performance cannot be maximized with respect to all of these objectives at the same time, since some of them are conflicting. Therefore, good vacuum filter operation represents a compromise between these objectives in which filter performance is optimized for a particular application.

Process Monitoring

The criteria used to evaluate vacuum filter performance are solids concentration or water content of the cake, efficiency of solids removal, and filter yield. The efficiency of solids removal usually is expressed as the percent solids recovery (or solids capture) which is the mass ratio of dry cake solids produced by the filter to the dry sludge solids fed to the filter over a given period of time. A decrease in solids recovery means that more solids are passing through the filter medium. Since this usually results in higher solids concentrations in the filtrate, the efficiency of filtration is sometimes expressed as a function of the filtrate solids concentration, although the solids removed from the cloth by water sprays should also be accounted for. The filter yield refers to the amount of solids, on a dry weight basis, removed as part of the solids cake over a given period of time.

In order to evaluate vacuum filter performance and diagnose problems, a complete record of several operating parameters must be kept. These are summarized in Table 22.

This information should be recorded routinely, along with machine operating conditions such as drum speed, drum submergence, vacuum pressure, etc. It is particularly important that any changes in performance or operating conditions be recorded along with the time that they are made.

TABLE 22

VACUUM FILTRATION
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Feed sludge flowrate (GPM or L/min).	Daily	To determine flowrate.
2. Filtrate flowrate (gpm or L/min).	Weekly	To determine filter performance.
3. Total and suspended solids concentration in feed sludge slurry (mg/L).	Daily	To determine feed rate to filter.
4. Total solids concentration in solids cake (percent by weight).	Daily	To determine solids removal and filter efficiency.
5. Total and suspended solids concentration in filtrate (mg/L).	Daily	To determine solids loading in filtrate.
6. Concentration of chemical conditioners added to sludge (ppm or percent).	Weekly	To set conditioning requirements.
7. Feed rate for chemical conditioners (L/min or gpm).	Weekly	To set conditioning requirements.
8. Feed sludge temperature (°F or °C).	Daily	Temperature affects filterability.
9. Feed sludge pH.	Daily	High or low pH values can change solubility of particles.
10. Wash water flowrate (gpm or L/min).	Weekly	To determine volumes of liquid in mass balance.
11. Solids concentration in wash water (mg/L).	Weekly	To determine solids in wash water, solids removal, and filter efficiency.

Example Calculations

Example calculations of operating parameters are presented below. Consider a rotary belt vacuum filter for which the following data have been collected:

Feed sludge flow rate = 20 gpm
Filtrate flow rate = 18 gpm
Feed suspended solids = 40,000 mg/L (4.0 percent)
Filtrate suspended solids = 600 mg/L
Cake solids concentration = 300,000 mg/L (30 percent)
Cloth wash water spray = 6 gpm
Solids concentration in wash water = 4,900 mg/L

The solids feed rate (dry solids fed to the filter per hour) is calculated as follows:

$$\begin{aligned}\text{Solids feed rate} &= (\text{feed sludge flow rate})(\text{feed suspended solids})\\ &= (20\ \text{gpm})(60\ \text{min/hr})(3.785\ \text{L/gal})(40\ \text{g/L})(\text{kg}/10^3\ \text{g})\\ &= 182\ \text{kg/h} = 400\ \text{lb/hr}\end{aligned}$$

The solids removed (dry solids removed per hour) is calculated as follows:

$$\begin{aligned}\text{Solids removal} &= (\text{feed solids mass})-[(\text{filtrate solids mass})+\\ &\qquad (\text{wash water solids mass})]\\ &= 400\ \text{lb/hr} - [(18\ \text{gpm})(0.6\ \text{g/L})+(6\ \text{gpm})(4.9\ \text{g/L})] \times\\ &\qquad [(3.785\ \text{L/gal})(\text{lb}/454\ \text{g})(60\ \text{min/hr})]\\ &= 380\ \text{lb/hr}\end{aligned}$$

The filter efficiency, expressed as percent solids recovered, is calculated as follows:

$$\text{Filter efficiency (\%)} = \frac{\text{Solids removal}}{\text{Solids feed rate}} \times 100$$

Filter efficiency = (380)/(400) x 100 = 95.0 percent

Process Control Strategies

The operation and performance of a vacuum filter is determined by several variables that are related either to the machine itself (machine variables) or to the specific sludge dewatering application (process variables). Among these are the following:

Machine Variables	Process Variables
Vacuum Pressure	Sludge Characteristics
Drum Speed	Chemical Addition
Drum Submergence	Solids Concentration
Filter Medium	Sludge Feed Rate
Tank Agitation	Temperature
Spray Water Pressure	pH
Position of Doctor Blades	

Machine Variables--

One of the most important machine-related variables is the vacuum pressure applied during formation and drying of the sludge cake. Within limits, the filter yield can be increased by increasing the vacuum since a higher vacuum generally results in greater cake thickness during the formation process. Practical limits usually are encountered at vacuum pressures of about 15 inches of mercury, since energy requirements increase rapidly with higher operating pressures. Further, many wastewater sludges are highly compressible, though this is not true for all types of sludge, and under higher vacuums these sludges form an impervious cake that is difficult to dewater. In such a case, increased vacuum pressures may reduce filter yield.

The drum speed, or the rate at which the filter drum rotates, affects both cake formation and cake drying operations. As the drum speed is reduced, the cake has a longer period of time to dewater, resulting in a drier cake. However, reducing drum speed reduces filter yield so that less sludge can be dewatered in any given period of time. Conversely, an increase in the drum speed results in a higher filter yield since more medium is passed through the cake formation zone during any given period of time. A wetter cake also results, however, since the sludge cake spends less time in the cake drying zone.

The degree to which the filter drum is submerged in the sludge vat, referred to as drum submergence, usually is expressed as a percentage of the drum circumference or filter medium surface area (the difference between these is a constant value). Drum submergence normally can be varied between 15 and 25 percent. An increase in submergence increases the cake formation area (and therefore cake formation time) but reduces the area (and time) available for cake drying; this usually results in a wetter but thicker cake. Decreasing the drum submergence produces a thinner but drier cake. A minimum submergence must be maintained to prevent vacuum on the filter from being broken.

Probably the most important machine variable is the filter medium itself. Selection of a filter medium suitable for use in a particular application is one of the most critical design considerations since it can determine the operating and performance limits of the vacuum filter. Materials which have been used as fabric media include cotton, rayon, acrylic, polyolefin, polyester, polypropylene, and nylon. Metal wire or mesh media also have been used, as have stainless steel coil springs. All of these media can be categorized as open or tight, with open media having larger size pores through which small solid particles can pass. Although a tight filter medium will remove a higher percentage of fine particles, thereby increasing filter efficiency, it can blind or stop up completely making filtration impossible. Spray washing of the media after cake discharge helps to prevent the build-up of fine particles which might otherwise blind the filter media. The characteristics of the filter medium usually change with use as it becomes worn or partially blinded with solids. While such changes usually occur gradually, it can eventually become necessary to replace the medium. Occasionally the medium type has to be changed, either to improve filter performance or because the previously used medium is not available. Whenever the filter medium is changed, and particularly when a different type of medium is used, the operation and performance of the vacuum filter can be expected to change also; sometimes these changes are significant.

Two machine variables that affect solids removal from the filter media are the pressure of the water sprays and the position of the doctor blades. Both are of critical importance and very minor adjustments can result in improved or diminished performance. Optimization of water spray pressure and doctor blade position is a matter of operating experience.

The final machine variable requiring discussion is the degree of agitation provided in the sludge vat through which the filter drum rotates. Agitation is required to prevent solids from settling, and some minimum level needed to meet this objective must be determined from operating experience. However, too much agitation can result in shearing or break-up of the sludge floc resulting in a lower filter efficiency and higher solids levels in the filtrate.

Process Variables--

The physical and chemical characteristics of the sludge to be dewatered together represent the single most important process variable affecting vacuum filtration. Different sludges exhibit dramatically different dewatering characteristics. Among the factors that determine filterability are the size, shape, density, and electrical charge of solid particles, viscosity of the liquid, and compressibility of the sludge solids. Generally these factors are not directly under the operator's control since they result from optimization of upstream treatment processes.

To compensate for poor filtering characteristics or to increase cake solids concentration, polymers and other chemicals often are added to the sludge prior to filtration. These may be required to help in cake formation and/or cake drying. Polymers and other coagulant aids promote flocculation, which increases particle size and improves filter efficiency. Filtering aids such as lime, diatomaceous earth, clay, fly ash, and other materials can be mixed with the sludge to improve solids recovery, facilitate good cake formation, and reduce sludge compressibility (which helps in cake drying). Selecting the proper coagulants and filter aids for a particular application is based upon jar tests, while optimizing their use is a matter of operating experience. Optimization of chemical usage is important since chemical cost usually represents the greatest single operating cost associated with vacuum filtration.

Another process-related variable is the solids concentration of the feed sludge. Up to a point, a higher solids concentration in the feed sludge usually results in a drier cake discharge and a higher filter yield. Another advantage of higher feed solids levels is that chemical requirements for sludge conditioning often are reduced. For these reasons, vacuum filters are sometimes preceded by gravity thickeners or centrifuges that increase the sludge solids concentration. Changes in the operation of upstream thickeners, centrifuges, or even clarifiers can improve filter performance if the changes increase the concentration of solids in the feed sludge. However, there are practical limits as to how high the feed solids concentration can be, as determined when pumping, mixing, and other problems begin to occur. The maximum solids concentration usually fed to vacuum filters is from 8 to 10 percent; above these numbers cake formation becomes difficult.

TYPICAL PERFORMANCE VALUES

The most important factor affecting the performance of a vacuum filter is the type of sludge being dewatered. If sodium hydroxide is used for pH adjustment to precipitate metal hydroxides, a light, slimy, and relatively difficult to dewater sludge will result. One of the main problems caused by this type of sludge is that it can blind the filter medium and form an impermeable cake that dewaters poorly. These problems usually can be overcome, however, by using proper conditioning agents, such as polymers and filter aids.

When lime is used for precipitation of metals, the amount of excess lime determines the dewatering characteristics of the sludge. When very little or no excess lime is added, most of the sludge formed will be metal hydroxides. If considerable excess lime is used, a large amount of calcium carbonate will be present in the sludge, making it heavier and more easily dewatered, since calcium carbonate sludges tend to form much more permeable cakes.

Table 23 gives typical performance values for rotary vacuum filters applied to both metal hydroxide and lime-carbonate sludges.

TROUBLESHOOTING GUIDE

The problems which are commonly associated with vacuum filter operations have been summarized in the form of a troubleshooting guide in Table 24. This is a general guide and some parts of the vacuum filtration system may have unique operating problems; these are usually addressed in the manufacturer's literature.

Vacuum filtration is one of the more difficult wastewater treatment processes to operate, because of the number of variables which affect performance. Therefore, whether diagnosing operating problems or optimizing filter performance, it is important to change only a single variable at a time. Otherwise, the cause of a problem (or its solution) cannot be determined with certainty. It is especially important that all other variables be held constant when determining optimum dosages for sludge conditioning.

TABLE 23
TYPICAL PERFORMANCE VALUES FOR VACUUM FILTRATION DEWATERING

Type of Sludge	Feed Solids Concentration (%)	Cake Solids Concentration (%)	Solids Recovery (%)	Typical Conditioning Chemicals
Metal Hydroxide				
- without conditioning	2-6	15-25	85-95	Lime; Diatomaceous Earth Anionic Polymers
- with conditioning	4-8	20-30	90-95	
High $CaCO_3$				
- without conditioning	2-8	20-30	90-95	Anionic Polymers Diatomaceous Earth
- with conditioning	6-10	30-45	95+	

TABLE 24
VACUUM FILTRATION
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Thin cake, poor dewatering.			
1a. Filter media blinding.	- Digest media and check spray washes.	- To determine if blinding is occurring and if it is caused by insufficient washing.	- Adjust spray washes or, if necessary, shut down filter and clean media.
1b. Improper chemical dosage.	- Check chemical addition system for malfunction.	- If no problems with equipment, the optimum dosage may have changed.	- Repair or adjust chemical addition system or, if necessary, determine new optimum dosage rates.
1c. Inadequate vacuum.	- Vacuum gauges and input for leaks or broken seals.	- To isolate the problem.	- Repair or adjust vacuum system to achieve desired vacuum.
1d. Drum speed too high.	- Drum speed and operating records.	- To determine if a change has occurred.	- Reduce drum speed if necessary.
1e. Drum submergence too low.	- Drum submergence and operating records.	- To determine if a change has occurred.	- Increase drum submergence to get thicker cake, decrease it to get drier cake.
1f. Feed sludge solids concentration has decreased.	- Solids feed rate and operating records.	- If solids have decreased, different operating conditions may be required.	- Determine if the solids level can be increased by changes in upstream processes. Otherwise, new operating conditions will have to be determined.
OPERATING PROBLEM 2: High solids in filtrate - low efficiency.			
2a. Improper chemical dosage.	- Check chemical addition system for malfunction.	- If no problems with equipment, the optimum dosage may have changed.	- Repair or adjust chemical addition system or, if necessary, determine new dosage rates.

TABLE 24
(Continued)
VACUUM FILTRATION
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
2b. Wrong type of media.	- Filter leaf tests.	- To select better media.	- Change media type.
OPERATING PROBLEM 3: Vacuum pump stops.			
3a. Lack of power.	- Check to see if heater tripped.	- Motor overload will trip heater.	- Determine cause of overload. Restart after cooling period.
3b. Lack of seal water.	- Source of seal water.	- To insure adequate flow.	- Start seal water flow.
3c. Broken V-belt.	- V-belt.	- V-belt may be worn or broken.	- Replace V-belt.
OPERATING PROBLEM 4: Drum stops rotating.			
4a. Lack of power.	- Check to see if heater tripped.	- Motor overload will trip heater.	- Determine cause of overload. Restart after cooling period.
4b. Drive mechanism broken.	- Check belt, chain, gear, etc.	- To determine what is broken.	- Repair or replace broken part(s).
OPERATING PROBLEM 5: High vat level.			
5a. Feed rate too high.	- Feed rate, solids yield, and operating records.	- To determine if any changes have occurred.	- Lower feed rate or increase drum speed.
5b. Drum speed too slow.	- Drum speed, solid yield, and operating records.	- To determine if any changes have occurred.	- Increase drum speed or reduce feed rate.

TABLE 24
(Continued)
VACUUM FILTRATION
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
5c. Improper chemical dosage - poor cake formation.	- Check chemical addition equipment for malfunction.	- If no problems with equipment, optimum dosages may have changed.	- Repair or adjust chemical addition system and, if necessary, determine new dosage rates.
5d. Filtrate pump off or clogged.	- Check filtrate pump and discharge.	- If on, it may be clogged.	- Turn on pump or unclog it.
5e. Drain line clogged.	- Drain line for flow.	- Drain line may stop flow.	- Clear drain line.
5f. Vacuum pump stopped.	- See Item 3.	- See Item 3.	- See Item 3.
5g. Seal strips missing.	- Drum interior.	- Loss of vacuum would prevent removal of filtrate.	- Replace seal strips.
OPERATING PROBLEM 6: Low vat level.			
6a. Feed rate too low.	- Feed rate, solids yield, operating records.	- Cake forms faster than solids applied to filter.	- Increase feed rate or decrease drum speed.
6b. Vat drain valve open.	- Vat drain valve.	- Open valve can drain vat.	- Close vat drain valve.
OPERATING PROBLEM 7: Filtrate receiver vibrating.			
7a. Filtrate pump is clogged.	- Check pump outlet for flow.	- Flow indicates possible clog.	- Turn off pump and clean it.
7b. Loose bolts or other parts.	- Check gaskets, inpaction plates, mounting, etc.	- Damage can result.	- Tighten loose parts; replace broken parts.
7c. Check to see if ball valve in filtrate pump or suction line is worn.	- Check ball valve.	- Worn ball valves can cause vibrations.	- Replace worn parts.

TABLE 24
(Continued)
VACUUM FILTRATION
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
7d. Air leaks in suction line.	- Impact line for leaks.	- Leaks in air line can cause vibrations.	- Seal leaks.
7e. Dirty drum face.	- Check drum face.	- Uneven vacuum results in pressure surges.	- Clean off drum face with with hose.
7f. Seal strips missing.	- Check drum interior.	- Uneven vacuum results in surges.	- Replace seal strips.
OPERATING PROBLEM 8: High amperage draw by vacuum pump.			
8a. Filtrate pump clogged.	- Filtrate pump output for flow.	- Vacuum pump drawing water from receiver.	- Turn pump off and clean.
8b. High vat level.	- See Item 6.	- See Item 6.	- See Item 6.
8c. Cooling water flow to vacuum pump too high.	- Cooling water flow.	-	- Decrease cooling water flow.
8d. Blinding of media causing high vacuum pressure.	- Check media and spray washer.	- To determine if media is soiled.	- Adjust spray washer and clean media, if necessary.
8e. Highly compressible sludge forming impermeable cake.	- Cake dryness and consistency. Check chemical addition system.	- May require addition of lime or other filter aid to improve sludge characteristics.	- Adjust chemical addition rates to improve cake characteristics.
OPERATING PROBLEM 9: Scale buildup on equipment.			
9a. High dosage of lime.	- pH adjustment to determine if excessive lime is added.	- High lime dosages or presence of unreacted lime may cause scale.	- Fine tune lime dosage (see pH adjustment and metal precipitation.)

TABLE 24
(Continued)
VACUUM FILTRATION
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
9b. $CaCO_3$ is precipitating out of solution.	- Influent calcium concentration and calcium solubility at operating pH.	- If influent calcium concentration is greater than solubility, then scale will form.	- Fine tune lime dosage, operate pH adjustment at different pH or decrease retention time of sludge in equipment by washing thoroughly with muriatic acid after operation.

SECTION 16

PRESSURE FILTRATION FOR DEWATERING

INTRODUCTION

Pressure filtration is a process used for dewatering sludges generated during wastewater treatment. Pressure filtration results in the generation of two products: a relatively clear liquid, called the filtrate, and a solids cake that is suitable for direct disposal. Compared to other mechanical dewatering processes, pressure filtration generally achieves the driest solids cake for any particular sludge. There is a cost associated with improved performance, however, as pressure filters are usually more expensive to operate than other types of dewatering equipment. Generally, but not always, pressure filters used for sludge dewatering are preceded by a gravity thickener or a centrifuge to increase the solids concentration of the sludge fed to the filter. Since pressure filters are designed and operated as batch processes, it may be important to reduce sludge volume by thickening prior to filtration.

THEORY OF OPERATION

The basic principle by which pressure filtration works is the same as for vacuum filtration: solids are separated from a liquid by passing the liquid through a porous medium on which the solids remain, eventually building up to form a cake that is removed for disposal. This process is much like what happens when sludge is applied to a sand drying bed. Water drains from the sludge into the sand leaving behind a concentrated solids layer. Given time, the force of gravity will cause enough water to drain out so that a sludge cake will form which can be handled and disposed of as a solid. In vacuum filters, a negative pressure differential that is equivalent to about 1000 times that of sand drying is applied to speed up the drying process. Pressure filters apply even greater forces to the sludge--up to 20,000 times the pressure differential of sand drying--which results in an even drier solids cake.

Almost all pressure filters used in sludge dewatering applications are designed to operate in a batch mode, as opposed to continuous operation. The usual sequence of events is as follows. First, the sludge slurry is applied to the filter and a sludge cake is formed on the filter medium as the filtrate passes through it and is removed. As additional sludge is pumped into the filter, the cake grows thicker and the backpressure increases. Eventually a point is reached when the sludge feed pumps are stopped. This point is based either upon time, decrease in feedrate, or operating pressures. Depending upon the type of filter, a cake compression step may follow, in which additional water is removed from the cake. Any remaining sludge slurry is then drained from the filter, after which the filter is opened to expose and discharge the solids cake. Once the cake has been removed and the media cleaned (if necessary), the filter is closed and the next cycle can begin.

Some filters and some types of sludge require that additional steps be performed. For example, to prevent blinding of the media, to improve solids capture, and to allow easy cake removal, it may be necessary to apply a precoat to the filter media before introducing the sludge. Precoating is done often when a greasy or sticky sludge, e.g., metal hydroxide, is being dewatered.

Sludge characteristics can affect dewaterability by pressure filtration just as they affect vacuum filtration. Generally, the much higher operating pressures compensate for poor sludge characteristics, although there are exeptions to this rule. Chemical conditioning with polymers or inorganic chemicals may be necessary to improve the sludge compressibility (resulting in a drier cake) and achieve a good quality filtrate. Sludge conditioning may also be necesary to get good cake release.

DESCRIPTION OF EQUIPMENT

As with vacuum filtration, the formation of a solids cake and the fact that solids are removed primarily on the surface of the filter medium rather than throughout its depth are two features that distinguish pressure filtration for sludge dewatering from other filtration processes. This distinction is important since pressure filters are used in other applications, such as in cartridge filters and strainers used online for the removal of solids from liquid streams. Since such types of pressure filters are not used in sludge handling and treatment operations, they will not be discussed in this section of the manual.

Batch pressure filters can be divided into three major groups:

(1) Filter Presses--including plate-and-frame presses and recessed-plate presses,

(2) Leaf, Plate, and Candle (Tubular) Filters--filters which take their names from the shape or orientation of the surfaces that collect the filter cake,

(3) Variable-Volume Filters--in which a cake is formed by pressure filtration and then compressed to expel the excess water remaining in it.

The distinction between these groups is somewhat arbitrary and different people may consider the same kind of filter to belong in different groups. These points are not important, however, since all operate on the same basic principles.

Filter Presses

Filter presses represent the most common type of pressure filters and consist of numerous plates with corrugated surfaces over which the filter medium is draped, as shown in Figures 29 and 30. The filter medium is usually in the form of woven cloth and often is made of synthetic monofilament fiber. The operating pressure is created by pumps

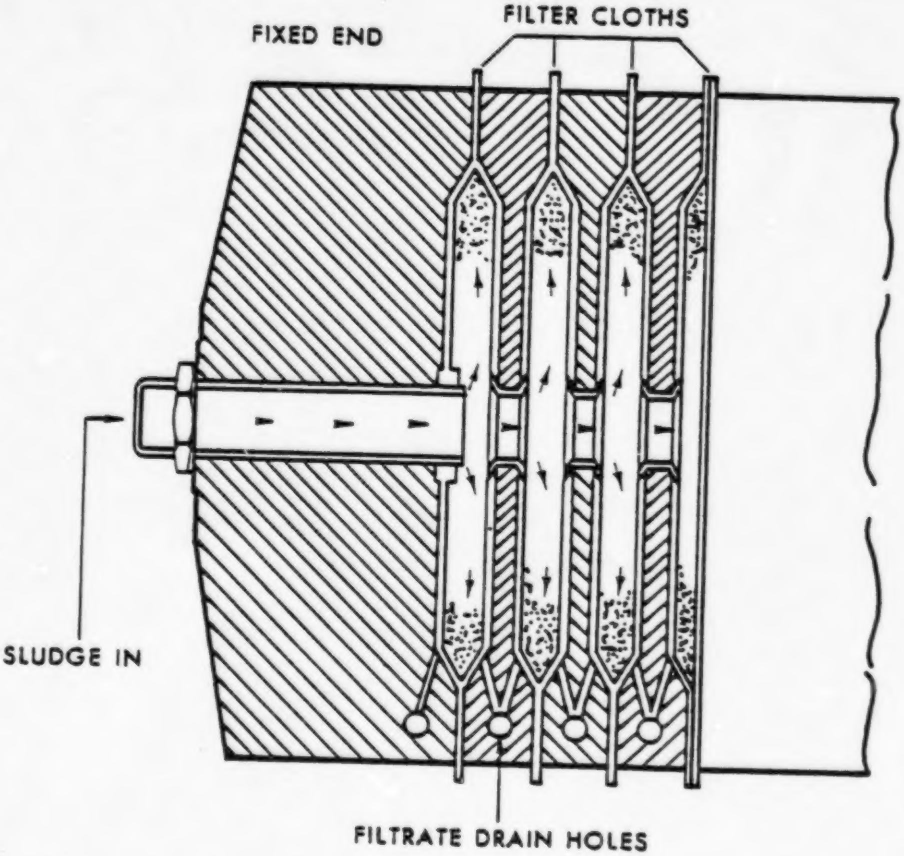
FIXED END
FILTER CLOTHS
SLUDGE IN
FILTRATE DRAIN HOLES

Figure 29. **Cutaway view of a filter press.**

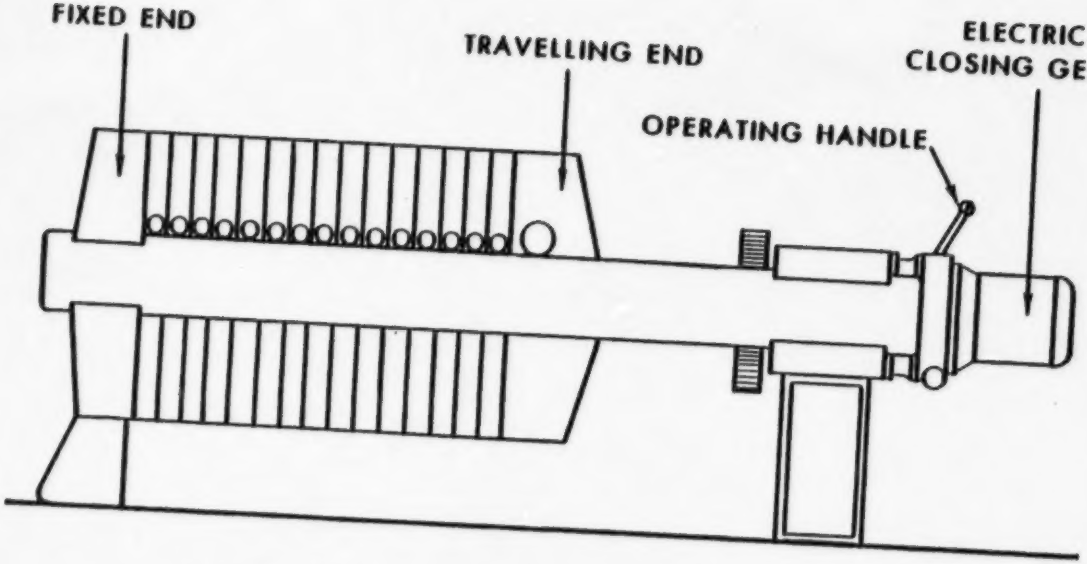
FIXED END
TRAVELLING END
ELECTRIC CLOSING GEAR
OPERATING HANDLE

Figure 30. **Side view of a filter press.**

which introduce the sludge slurry between layers of the filter medium. One end of the press is fixed while the other end can be moved to allow separation of the plates and discharge of the solids cake. There are two main types of filter presses, the plate and frame press and the recessed plate press.

In the plate-and-frame press, the plates are separated by hollow frames which are covered with the filter medium. The alternating plates and frames are held tightly together during filter operation to form a continuous unit. Sludge is introduced into the hollow frames and the solids cake then forms on the filter medium (within the frames). The filtrate passes through and drains along the corrugations in the plate from which, depending upon the individual filter, it may drain directly out the bottom of each plate or may flow through a channel that runs the length of the press. Sludge feed continues until the frames are full, as judged by time, decrease in feedrate, or increase in backpressure. At the end of the batch, the press usually is drained of any remaining liquid after which it is opened and the plates and frames separated to release the solids cake.

Another type of filter press is the recessed-plate press. In this type of press, the plates are shaped so that a hollow space exists between them in which the solids cake forms. There are no separate hollow frames between adjacent plates. Sludge enters the press through ports in the center of the plates. Otherwise, the recessed-plate press looks and is operated just like the plate and frame press.

Leaf, Plate, and Candle Filters

Pressure filters in this group have a number of hollow filter elements suspended either vertically or horizontally within a closed vessel. The shape of these elements is what gives the various types of filters in this group their names. These filter elements are often covered with a woven cloth filter medium, although there are some applications in which the surface of the filter element also serves as the filter medium. Sludge flows into the vessel under pressure and liquid (filtrate) flows out through the hollow elements to a common discharge manifold. In the process, the solids left behind on the filter medium build up to form a cake which eventually causes the operating pressures to increase and sludge feedrates to decrease.

At the end of an operating cycle, the vessel is depressurized and any remaining slurry is drained. The filter is then opened and the filter elements are removed (usually this process is automatic). The cake is then removed from the filter elements by one or more of several methods including vibration, scraping, compressed air blow-back, centrifugal force, and leaf rotation.

Variable-Volume Filters

The third type of pressure filter first forms a solids cake, usually by pressure filtration, and then compresses it to expel additional water contained in the wet cake. The purpose is to produce a drier cake than in conventional filter presses. The variable-volume name refers to the fact that in these filters the size of the chamber in which the cake is formed changes during operation by the movement of a diaphragm. In fact, these filters are often referred to as diaphram filters. The most common type of variable-volume diaphragm pressure filter somewhat resembles a recessed plate filter press. All of the filters of this type operate on the same basic principle, although there are numerous variations in the individual steps of an operating cycle.

OPERATIONAL PROCEDURES

The main objective of using pressure filters for dewatering is to produce a solids cake for discharge that has a very high solids concentration. High solids concentration is important since the moisture content of the sludge directly affects hauling and disposal costs--it is certainly not desirable to pay more for hauling water in the form of a wet cake, if a drier cake can be achieved. To achieve a high concentration in the cake, very high operating pressures are required, as is a tight filter medium (one with very small pore sizes). As a result of these features, filtrate quality is usually not considered to be a performance limiting factor in pressure filtration. More important is the filter yield, or mass of solids (dry weight) that can be dewatered in a given amount of time. An increase in the yield usually requires that the batch cycle time be decreased, which in turn results in a wetter cake. Therefore, the objective of pressure filter operation is to maximize cake solids while still achieving a filter yield that is sufficient to process all the sludge generated in upstream treatment processes.

Process Monitoring

Filter press performance is measured by the solids content in the feed sludge, required chemical conditioning dosages, cake solids content, total cycle time, solids capture, and the filter yield. Of these, the last two require some explanation.

Solids capture, also called solids recovery, is the mass ratio of cake (or thickened sludge) solids to the feed solids for a single batch run. A low solids capture means that solids are lost in the filtrate and are not part of the solids discharge. The solids yield (removal) refers to the amount of solids, on a dry weight basis, that can be removed by a pressure filter during a single batch run. The yield multiplied by the number of batches run must equal or exceed the sludge generation rate if solids are not to accumulate upstream in the treatment system.

The performance parameters discussed above are all interrelated; for example, as the feed solids content increases, the required chemical dosages and total cycle time usually decrease, while the filter yield or throughput usually increases. As the chemical conditioning dosage is increased to the optimum level, the cake solids content, solids capture, and yield all increase, while the cycle time decreases.

In order to evaluate pressure filter performance and diagnose operating problems, a complete record of several operating parameters must be kept. These are listed in Table 25.

This information should be recorded routinely, preferably for each batch. It is especially important that changes in pressure settings, filter cycle time settings, chemical conditioning dosages, etc. be recorded along with the time (batch number) that they are made. In this way a useful record of the effects of process variables on performance will be developed.

Example Calculations

Consider a pressure filter for which the following data have been collected:

Volume of sludge fed per run = 10,000 gallons
Volume of filtrate produced per run = 9,000 gallons
Feed suspended solids = 40,000 mg/L (4 percent)
Filtrate suspended solids = 0.6 g/L
Cake solids concentration = 400,000 mg/L (40 percent)

Sludge feed volume and filtrate volume per run are functions of cycle time and maximum operating pressures. The solids fed per filter run (dry weight basis) is calculated as follows:

Solids fed per run = (Volume of sludge fed)(Feed suspended solids)
= (10,000 gallons (3.785 L/gal)(40 g/L)
= 1514 Kg = 3335 lbs.

The solids lost per filter run is calculated as follows:

Solids lost per run = (Volume of filtrate)(Filtrate suspended solids)
= (9,000 gallons)(3.785)(0.6 g/L)
= 20 Kg = 45 lbs.

TABLE 25

PRESSURE FILTRATION
PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Batch cycle times (minutes).	Per batch	To determine system performance.
2. Volume of sludge fed per batch (gallons or liters).	Per batch	To determine solids feed rate, solids capture, and solids yield.
3. Total and suspended solids in feed slurry (mg/L or percent by weight).	Per batch	See Comment 2.
4. Feed slurry back-pressure (psi).	Per batch	To determine pressure history during operation.
5. Machine hydraulic pressure (psi).	Per batch	To assess system operation.
6. Filtrate flowrate (gpm or L/min).	Per batch	To correlate filtrate solids to solids capture.
7. Filtrate suspended solids concentration.	Per batch	See Comment 6.
8. Total solids concentration of cake (percent by weight).	Per batch	To determine percent capture and solids yield.
9. Dosage rate for chemical conditions and filter aids (mg/L, ppm, or percent by weight)	Per batch	To determine conditioning requirements.
10. Feed sludge temperature ($^{\circ}$F or $^{\circ}$C).	Per batch	Temperature affects solubility of particles.
11. Feed sludge pH.	Per batch	pH affects solubility of particles.

The solids yield for a single run is calculated as follows:

Solids yield = (Solids fed per run) - (Solids lost per run)
= 3335 - 45
= 3,290 lbs.

The solids capture for a single run is calculated as follows:

Solids capture (percent) = (Solids yield)/(Solids fed per run) x 100
= (3,290/3,335) x 100
= 98.7 %

Process Control Strategies

The operation and performance of pressure filters for sludge dewatering is determined by a relatively small number of variables, compared to other mechanical dewatering processes. Although control of the process may be manual, semi-automatic, or fully automatic, the basic operating cycle and machine related variables are the same.

A typical cycle begins with the closing of the filter, after which sludge is pumped into the press until it is essentially full of cake. Sludge pumping then continues with increasing back pressures and decreasing sludge flows. The end of the sludge feed step in the filter cycle is determined when back-pressures reach the designed maximum (usually 100 psi, but sometimes as much as 220-250 psi). To reach this point typically takes 20 to 30 minutes. The high back-pressure is then maintained for a period of usually one to four hours, during which time additional water is removed from the cake as filtrate. Based upon either time or filtrate flow rate (which becomes nearly zero), the filter cycle is ended by relieving the pressure, opening the filter, and removing the solids cake. The only real variation on this cycle is when a variable volume filter is used. In this case, the high-pressure holding time is much less, and it is followed by an additional step in which diaphragms behind the filter media are expanded by high pressure air or water to force out water and further concentrate solids in the cake.

Therefore, the only machine variables that are under operator control are the time settings for each step in the filter cycle and, in the case of some machines, the operating back-pressures (which are determined by the sludge feed pumps). Cycle time is usually the main machine variable affecting filter yield. In rare cases, it may be necessary to select a different type of filter medium to improve performance, particularly if the sludge cake is not removed easily from the medium or high filtrate solids concentrations are a problem.

Of the process (non-machine) variables, the most obvious are those related to the sludge. The sludge characteristics that improve dewatering by vacuum filtration are also advantageous for pressure filtration. Because of the greater energy involved in pressure filtration, however, the sludge variables are considered to be less of a factor in dewatering performance.

However, the variable over which the operator can exercise complete control is chemical conditioning. The wide range of chemicals used in pressure filtration also are similar to those for vacuum filtration. Filter presses usually require a filter aid and/or a precoat material to reduce blinding and to facilitate release of the cake from the media during the unloading stage. Incinerator ash or diatomaceous earth are typical precoat materials that are added just before sludge charging.

Precoat application is a critical step in the batch operating cycle, and manufacturers' recommendations for mixing and applying precoat must be followed explicitly to achieve good results. A poor precoat can cause several problems, one of which is high solids in the filtrate. However, the most important reason for achieving a good precoat is to insure good solids cake release from the media. Otherwise, it will be necessary to wash the medium with high pressure water sprays after each batch to prevent media blinding and maintain performance. This step can be extremely time consuming, in addition to defeating the whole purpose of filtration by diluting with water the cake solids that remain stuck on the media.

Other operating procedures include routine water washing of the filter media to prevent blinding and to maintain filter yield. Occasionally acid washing with dilute muriatic acid is necessary to remove calcium carbonate scale that forms on the media. It is also occasionally necessary to replace worn media, although this is usually only done after filter yields drop to the point that water and acid cleaning are no longer sufficient to maintain acceptable yields.

TYPICAL PERFORMANCE VALUES

Most sludges from metals finishing wastewater treatment dewater very well in pressure filters, provided proper precoat application and chemical conditioning are used. Typically, a solids cake from 30 to 50 percent by weight is achieved, with a solids recovery of 95 to 99 percent.

TROUBLESHOOTING GUIDE

The troubleshooting guide for the pressure filtration process is presented in Table 26. Major problem areas include filter blinding, improper sludge conditioning, and high cake moisture content. Both chemical and mechanical methods of solving these problems are considered.

TABLE 26
PRESSURE FILTRATION FOR DEWATERING
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Low cake solids concentration (high moisture content in cake).			
1a. Filter cycle time too short.	- Operating records to correlate filtrate flow and cycle time with cake moisture content.	- To determine if optimum operating conditions have changed.	- Increase filter cycle time.
1b. Improper sludge conditioning.	- Chemical and filter aid feed systems and mixers.	- To determine if mechanical problems exist or if a dosage change is required.	- Repair any malfunctioning equipment or change dosage of either chemicals or filter aid and re-evaluate filter performance.
OPERATING PROBLEM 2: Cake discharge is difficult or incomplete.			
2a. Inadequate precoat on media.	- Precoat slurry mixing and pumping system.	- To determine if a mechanical problem exists or if precoat mix or application procedure should be changed.	- Repair any malfunctioning equipment or change either precoat mix or application procedure. Follow manufacturers' recommendations for initial changes.
2b. Improper sludge conditioning.	- See Item 1b.	- See Item 1b.	- See Item 1b.
OPERATING PROBLEM 3: Filter cycle time excessively long.			
3a. Feed solids concentration too low.	- Operation of upstream thickening process. Check solids feed rate with historical data.	- Inadequate thickening can result in an excessive time to build up solids cake.	- If possible, improve performance of upstream thickening operation to achieve higher feed solids; otherwise, see Item 3b.
3b. Improper sludge conditioning.	- See Item 1b.	- See Item 1b.	- See Item 1b.

TABLE 26
(Continued)
PRESSURE FILTRATION FOR DEWATERING
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 4: Frequent media blinding, failure to develop cake on media.			
4a. Inadequate precoat on media.	- See Item 2a.	- See Item 2a.	- See Item 2a.
4b. Initial sludge feed rate too high (where no precoat is used).	- Feed sludge pumping rates and correlate with previous performance.	- To establish whether lower pumping rates have previously resulted in less blinding and better cake formation.	- Keep initial feed rate low to develop cake slowly; or consider use of precoat if problems persist.
4c. Improper sludge conditioning.	- See Item 1b.	- See Item 1b.	- See Item 1b.
OPERATING PROBLEM 5: Pressures increasing during precoat application.			
5a. Filter media becoming blinded, possibly with carbonate scale.	- Filter media.	- To establish if blinding has occurred.	- Water wash filter media. Acid wash media to remove carbonate buildup.
5b. Improper sludge conditioning causing media blinding.	- See Item 1b. Also check for high moisture content in cake or increased filter cycle times.	- See Item 1b.	- See Item 1b.
5c. Improper precoat mix or feed procedure.	- See Item 2a. Also check manufacturer's recommended procedures for precoat application.	- See Item 2a.	- See Item 2a.
OPERATING PROBLEM 6: Solids cake sticks to conveying equipment after removal from filter.			
6a. Improper sludge conditioning.	- See Item 1b.	- See Item 1b.	- See Item 1b. Also may need to change to more inorganic chemicals (e.g. lime) or different filter aid material.

TABLE 26
(Continued)
PRESSURE FILTRATION FOR DEWATERING
TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 7: Failure to form adequate seal between plates.			
7a. Plates out of alignment.	- Check alignment.	- See Probable Cause.	- Realign plates.
7b. Inadequate skimming.	- Check stay bosses.	- See Probable Cause.	- Adjust skimming of stay bosses.
7c. Foreign object preventing a good seal.	- Open press and inspect sealing faces for foreign objects.	- See Probable Cause.	- Remove foreign object.

SECTION 17

CENTRIFUGATION

INTRODUCTION

Centrifugation is a process used for concentrating sludges generated during wastewater treatment. Often, centrifuges are used in place of gravity thickeners. Centrifuges have also been installed, usually following a thickener, as dewatering devices. The difference between thickening and dewatering depends upon the final water content of the sludge. The product of thickening is still a fluid that can be pumped, while the product of dewatering is a cake that can be handled as a solid and is transported by conveyers and dumpsters. Whether a sludge needs to be thickened only or dewatered prior to disposal depends upon many factors. Similarly, the objective of centrifugation (whether for thickening or dewatering) will be different from one facility to the next, although the basic principles and operating procedures are the same.

THEORY OF OPERATION

Centrifugation works on the same principle as gravity settling and thickening, except that the centrifugal forces which cause the particles to settle are much greater than the force of gravity. In a clarifier or thickener, the suspended solids which are more dense than water sink to the bottom of the tank leaving clear liquid above. In centrifuges, a rotating bowl acts as a highly effective settling chamber. When sludge is introduced into the bowl and is thrown against the inside wall, it forms a pool or layer of liquid. The suspended solids in this pool move toward the wall, as a result of their greater density, and leave behind a layer of clear liquid called the centrate. The centrate then is removed, leaving a thickened sludge or solids cake for further treatment or disposal. Since the same principle is involved as with other thickening devices, sludges that thicken poorly by gravity are generally more difficult to thicken and dewater by centrifugation. As is the case in gravity thickening, both polymers and chemical coagulants often are used to condition sludges prior to centrifugation.

DESCRIPTION OF EQUIPMENT

The method by which the centrate and solids are separated is the main difference between the many types of centrifuges used in wastewater treatment. The basic operating principles are the same for all, however. Three basic types of centrifuges have been used commonly for wastewater treatment applications in the metal finishing industry; the solid bowl decanter, the imperforate basket, and the disk-nozzle centrifuge. These will be discussed separately below.

Solid Bowl Decanter

The solid bowl decanter centrifuge, also sometimes called a scroll or conveyor centrifuge, is the most common type used for dewatering wastewater sludges. This type of centrifuge operates in a continuous or flow-through mode and consists of a rotating horizontal cylindrical bowl containing a screw type conveyor or scroll which also rotates, but at a slightly lower or higher speed than the bowl, as shown in Figure 31. The differential speed between the bowl and the conveyor is used to move the solids toward one end of the bowl for discharge. The bowl is usually a cylinder made of mild or stainless steel with a conical section at one end. The conical section is the discharge end for the sludge and serves as a dewatering beach or drying deck. Sludge enters the rotating bowl through a stationary feed pipe extending into the hollow shaft of the rotating conveyor and is distributed through ports in this hollow shaft into a pool within the rotating bowl.

There are two main types of solid bowl centrifuges. The most common is the counter-current type in which the solids cake and centrate

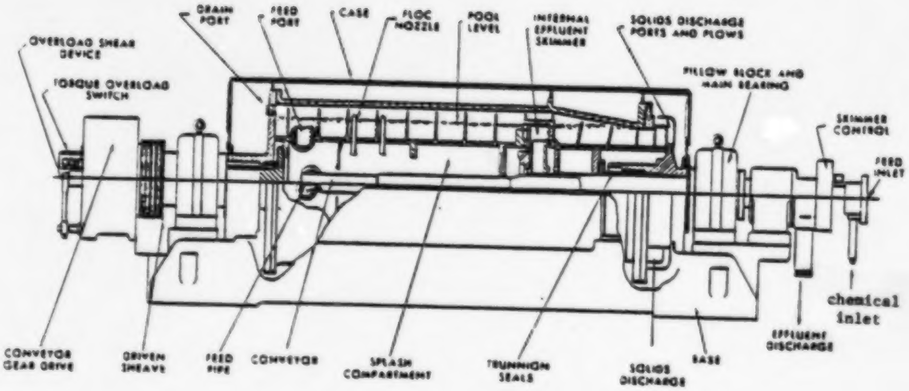
DRAIN PORT
FEED PORT
CASE
FLOC NOZZLE
POOL LEVEL
INTERNAL EFFLUENT SKIMMER
SOLIDS DISCHARGE PORTS AND FLOWS
OVERLOAD SHEAR DEVICE
TORQUE OVERLOAD SWITCH
PILLOW BLOCK AND MAIN BEARING
SKIMMER CONTROL
FEED INLET
chemical inlet
EFFLUENT DISCHARGE
CONVEYOR GEAR DRIVE
DRIVEN SHEAVE
FEED PIPE
CONVEYOR
SPLASH COMPARTMENT
TRUNNION SEALS
SOLIDS DISCHARGE
BASE

Figure 31. **Cross section of concurrent flow solid - bowl centrifuge.**

move toward opposite ends of the bowl for discharge. The centrate is decanted off the top of the liquid pool through a port or over a weir, the location of which can be adjusted to change the depth of the liquid within the bowl. In the other type of centrifuge, the concurrent flow type (Figure 31), the sludge slurry is introduced at the far end of the bowl from the dewatering beach and the sludge solids and centrate both flow in the same direction. The centrate is withdrawn by a skimming device or return tube located near the junction of the bowl and the beach. Clarified centrate then flows into channels inside the scroll hub and returns to the feed end of the machine where it is discharged over adjustable weir plates through discharge ports built into the bowl head.

Imperforate Basket Centrifuge

The imperforate basket centrifuge, also known as a knife-discharge centrifuge, is a semi-continuous feeding and solids discharging unit that rotates about a vertical axis, as shown in Figure 32. Sludge is fed into the bottom of the basket and sludge solids form a cake on the bowl walls as the unit rotates. The centrate is displaced over a baffle or weir at the top of the unit. Sludge feeding is continued either for a specific period of time or until the suspended solids in the centrate reach a predetermined concentration.

After sludge feeding is stopped, the centrifuge slows to about 70 rpm, and a plowing knife moves into position, either automatically or manually, to cut the sludge away from the walls; the sludge cake then drops through the open bottom of the basket. After plowing terminates, the centrifuge begins to accelerate and feed sludge again is introduced. At no time does the centrifuge actually stop rotating. Many units also have a skimming step which precedes plowing. A special skimmer nozzle swings into position to remove the low concentration solids which remain in the basket near the inside surface of the liquid pool. These are recycled back to an upstream process along with the centrate.

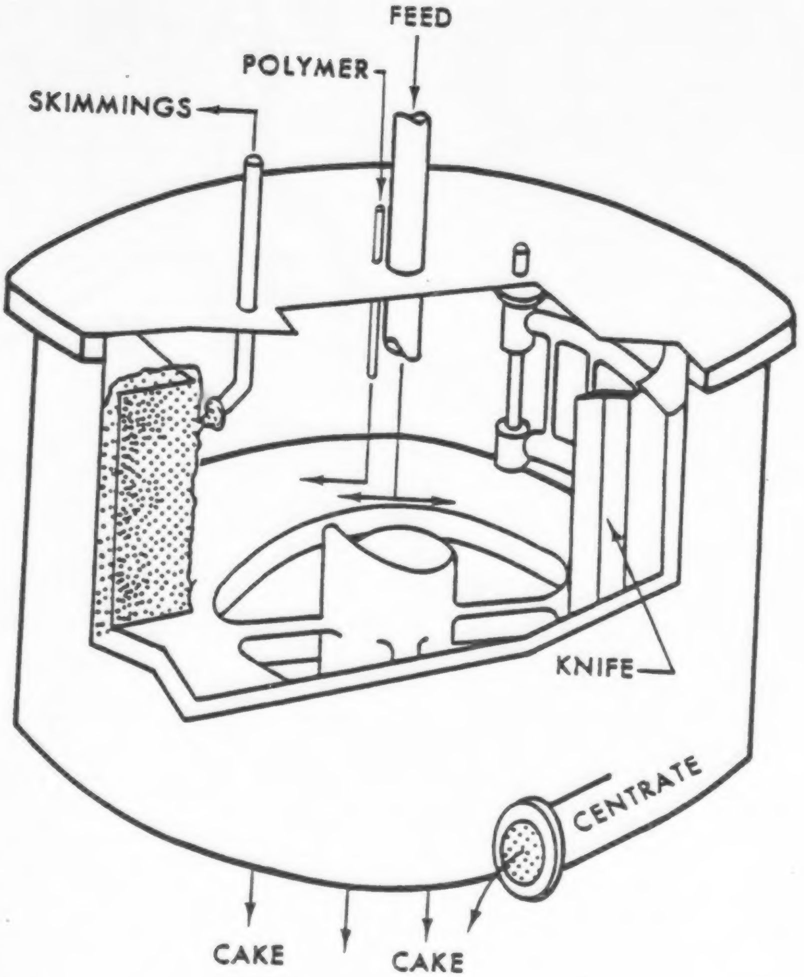
FEED
POLYMER
SKIMMINGS
KNIFE
CENTRATE
CAKE
CAKE

Figure 32. **Schematic diagram of a basket centrifuge.**

In smaller facilities, where the volume of sludge to be handled is less, centrifugation may be strictly a batch operation in which rotation stops completely after each batch is processed. In this case, operation is usually not automated and the equipment is somewhat simpler in design.

Although the cake solids concentration and yield are not as high for the basket centrifuge as for a solid bowl centrifuge, solids recovery is generally better and often less polymer and other conditioning chemicals are required. Obviously, the cake solids concentration must be considered as average solids content, since the solids content is maximum at the bowl wall and decreases toward the center.

Disk-Nozzle Centrifuge

The disk-nozzle centrifuge is a continuous-flow vertical bowl machine which contains a number of closely spaced disks against which the particulate solids settle, as shown in Figure 33. The feed slurry normally enters through the top although bottom feed is also possible, and passes down through a feedwell in the center of the rotor. An impeller within the rotor accelerates and distributes the feed slurry, filling the rotor interior. The heavier solids settle outward toward the circumference of the rotor under increasing centrifugal force. The liquid and the lighter particles flow inward through the cone-shaped disc stack. These lighter solids are settled out on the underside of the discs, where they agglomerate, slide down the discs, and migrate out to the nozzle region. The centrifugal action causes the solids to concentrate as they settle outward. At the outer rim of the rotor bowl, the high energy imparted to the fluid forces the concentrated material through the rotor nozzles.

Often, a portion of the thickened sludge discharge is recycled back into the concentrating chamber near the base of the rotor to increase the final concentration in the sludge and to help prevent plugging of the nozzles. In addition to providing a flushing action, the recycle also permits the use of larger nozzles which are less likely to plug.

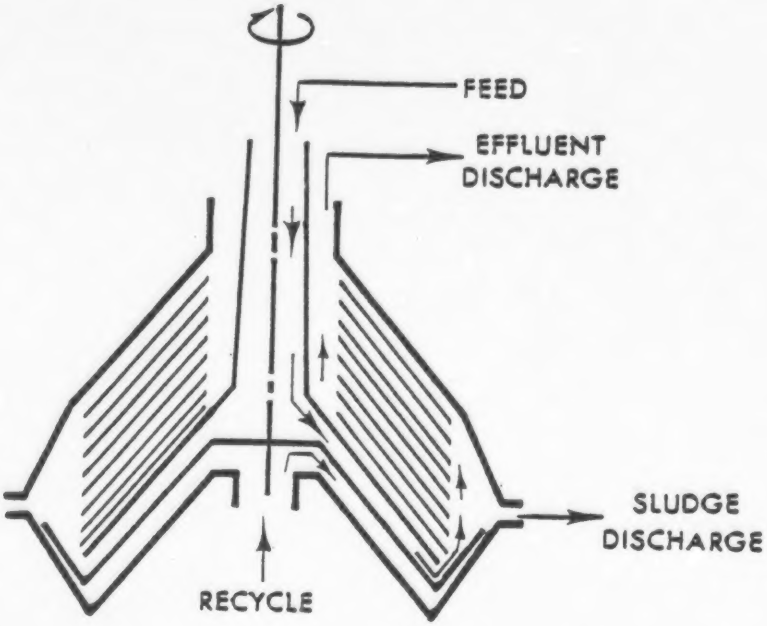
FEED
EFFLUENT DISCHARGE
SLUDGE DISCHARGE
RECYCLE

Figure 33. **Disc type centrifuge.**

Plugging or clogging of the nozzles or the space between disks (which are generally separated by only 1 to 2 mm) is the main reason that disk-nozzle centrifuges have not gained wider acceptance in wastewater treatment. However, for thickening sludges from the treatment of metal finishing wastes, which contain little or no fibrous or gritty material, they are gaining acceptance.

OPERATIONAL PROCEDURES

The purpose of centrifugation is to minimize both the water content of the thickened sludge or solids cake and the solids concentration in the centrate while maintaining sufficient machine throughput to prevent a buildup or accumulation of sludge in upstream treatment processes. Generally, efforts to increase the solids concentration result in a centrate of poorer quality, while improving centrate quality usually reduces the sludge or cake solids concentration. Acceptable limits on the solids content of the centrate are determined when the recycled centrate begins to interfere with the operation of other treatment processes or fine solids begin to build up to unacceptable levels in the sludge handling system. Although a high solids concentration and good centrate quality often can be achieved at the same time, to improve both may require that the machine throughput or solids yield be reduced and that the use of chemicals for conditioning be increased. There is a limit on how much the yield can be reduced, as solids must be removed for disposal as fast as they are generated or they will build up and affect the performance of other treatment processes. Similarly, there are limits on chemical usage since such usage represents a significant part of the total operating costs associated with centrifugation. Therefore, good centrifuge operation is a compromise between final solids concentration, centrate quality, solids loading or yield, and operating costs.

Process Monitoring

The main criteria used in evaluating centrifuge performance are concentration of the solids discharge, concentration of solids in the centrate, solids capture or recovery, and solids removal or yield (or machine throughput). Of these the last two require some explanation.

Solids capture, also called solids recovery, is the mass ratio of cake (or thickened sludge) solids to the feed solids over equal sampling periods. A lower solids capture means that a greater fraction of the feed solids are lost to the centrate and are not part of the solids discharge. For a constant solids feed rate, the result is a higher concentration of solids in the centrate.

The solids yield (removal) refers to the amount of solids, on a dry weight basis, that can be removed by the centrifuge during a given period of time. As a long term average, the yield must equal or exceed the solids feed rate if sludge solids are not to accumulate in the treatment system.

In order to evaluate centrifuge performance and diagnose problems, a complete record of several operating parameters must be kept. These are listed in Table 27.

The information listed in Table 27 should be recorded routinely, along with machine operating conditions such as bowl speed, weir settings or pool depth, sludge recycle rate, etc. It is particularly important that any changes in performance or operating conditions be recorded along with the time that they occur.

Example Calculations

Example calculations of operating parameters are presented below. Consider a continuous solid bowl centrifuge operation for which the following data have been collected:

Feed sludge flow rate = 40 gpm
Centrate flow rate = 36 gpm
Feed suspended solids = 40,000 mg/L (4.0 percent)
Centrate suspended solids = 2,250 mg/L (0.23 percent)

TABLE 27

CENTRIFUGATION PROCESS MONITORING REQUIREMENTS

Parameter	Frequency	Comment
1. Sludge flowrate or volume.	Daily	To determine solids feed rate.
2. Sludge suspended solids concentration.	Daily	To determine solids feed rate.
3. Dewatered cake suspended solids concentration.	Daily	To determine centrifugation dewatering performance.
4. Dewatered cake volume.	Daily	To determine volume of cake to be disposed.
5. Centrate flowrate.	Weekly	To determine solids capture.
6. Centrate suspended solids concentration.	Weekly	To determine solids capture.
7. pH, Temperature	Daily	To evaluate effects of pH and temperature.
8. Polymer type and dosage.	Weekly	To determine conditioning requirements.

Solids cake concentration = 350,000 mg/L (35 percent)
Polymer dosage rate = 2 lb/ton
Concentration of polymer feed = 1.0 percent

The solids feed rate (dry solids fed to centrifuge per hour) is calculated as follows:

Solids Feed Rate = (feed sludge flow rate) x (feed suspended solids)
= (40 gpm)(60 min/hr)(3.785 L/gal)x(40 g/L)
= 363 kg/hr = 800 lb/hr

Solids removed (dry solids per hour) is calculated as follows:

Solids removed = (feed solids mass applied) - (centrate solids mass)
= (800 lb/hr) - (2.25 g/L)(lb/454g)(36gpm)(3.7854 L/gal)(60min/hr)
= 760 lb/hr

Solids capture or solids recovery is calculated as follows:

Solids Capture = (760)/(800) x 100 = 94.9 percent

Process Control Strategies

The operation and performance of a centrifuge is determined by a number of variables that can be related either to the machine itself (machine variables) or the specific sludge thickening or dewatering application (process variables). Although these variables differ for various types of centrifuges, many are of general importance. Among them are the following.

Machine Variables

Centrifuge Design
Bowl Speed
Pool Depth
Conveyor Speed

Process Variables

Sludge Characteristics
Chemical Addition
Solids Concentration
Solids Feed Rate
Temperature
pH
Recycle of Sludge

These variables and the effect that these variables have on solids recovery and cake solids concentration are presented in Table 28.

Machine Variables--

Some of the most important machine variables are fixed by the centrifuge design and are not under operator control. Among these are the bowl length to diameter ratio, bowl angle or slope of the dewatering deck, scroll or conveyor design, flow patterns (concurrent or countercurrent), disk spacing, and nozzle diameter. Although important as design choices, a detailed discussion of these variables and their effects on the process will not be presented in this manual.

The rotational speed of the centrifuge is one of the most important factors affecting performance since centrifugal force speeds up the sedimentation process. An increase in bowl speed provides more gravity-settling force, thus providing greater clarification of the centrate and compaction of the solids. In solid bowl decanters, greater centrifugal forces also can help to squeeze water out of the sludge on the drainage deck, thereby producing a drier solids cake. Sometimes, higher bowl speeds can reduce polymer usage. If these advantages outweigh the increased power costs, operation at higher speeds can be beneficial.

There are problems with increasing bowl speeds, however. Higher speeds sometimes result in shearing of the sludge floc. Since smaller particles settle more slowly, higher bowl speeds can result in a higher concentration of suspended solids in the centrate. This problem can be avoided largely in machines where coagulant aids are added internally

TABLE 28
SUMMARY OF OPERATIONAL VARIABLES AFFECTING CENTRIFUGE PERFORMANCE

Variable	Effect of increase in variable on	
	% Solids Recovery	Cake Solids Concentration
Machine Variables		
Bowl Speed	Increase	Increase
Pool Depth	Increase	Decrease
Scrolling Speed	Decrease	Decrease
Process Variables		
Feed Rate	Decrease	Increase
Feed Concentration	Decrease	Increase
Temperature	Increase	Increase
Chemical Addition	Decrease	Increase
*Sludge Recycle	Decrease	Increase

* Disk-nozzle centrifuges only.

into the bowl and flocculation occurs after the solids are up to the bowl speed. Another problem with higher speeds, especially in solid bowl centrifuges with a conveyor or scroll, is that tremendous pressures are set up between the solids and the surfaces of scroll and bowl, tending to lock these two parts together. Further, with abrasive sludges, high friction and costly wear result. Some sludges, though not especially abrasive, have poor sliding characteristics and resist conveying. This resistance can impose high loads on the scroll and on the gear unit which drives it. Therefore, final adjustment of bowl speed must be a compromise between degree of clarification, degree of cake dryness, chemicals used, and costs of maintenance and power. Because of these and other complicating factors, bowl speed is not normally varied on most centrifuge models once a centrifuge is installed.

Pool depth affects the performance of both conveyor and basket centrifuges, while disk-nozzle centrifuges usually are designed to operate completely filled without a variable pool depth. Settling theory says that the best clarification (or solids capture) occurs when liquid depths are shallow, since the solid particles have a shorter distance to travel to be separated from the liquid. However, experience has shown there to be a limit to how shallow the pool can be and still maintain good solids capture. Too shallow a pool results in a high linear velocity through the centrifuge, a condition which causes turbulence that resuspends settled particles and prevents settling of very fine particles. In conveyor type centrifuges, the turbulence caused by the scroll also has more adverse effect on settleability when the pool depth is shallow. Since the residence time within the centrifuge is shorter when the pool depth is shallower, less time is available for flocculation to occur. This also can result in poorer centrate quality.

There are limits to how deep the liquid pool in a centrifuge can be, however. As settling theory predicts, increasing the depth too much can also cause a low solids capture and poor centrate quality since the particles must settle through a greater distance to be removed. There are also cases in which a shallow pool is desirable. In a solid bowl conveyor type centrifuge, lowering the pool exposes more of the drainage deck or beach area, and increases the time available for dewatering. This condition results in a drier solids cake.

With most centrifuges, pool depth is more easily changed than bowl speed, but still requires several hours of labor and down-time. Therefore, other remedies usually are tried first when a problem exists.

In solid bowl decanter centrifuges, the conveyor or scroll rotates at a slightly different speed (either faster or slower) than the bowl. This speed differential can normally be varied by adjusting gear ratios manually while the machine is not running. Some centrifuges are equipped with an automatic backdrive, making the differential speed relatively easy to change. Usually the pool depth is fixed in such machines. Conveyor speeds normally are designed or adjusted to the minimum that still provides sufficient conveying capacity.

Increasing the differential between the bowl speed and the scroll speed normally results in a wetter sludge cake and poorer solids recovery because of increased turbulence and reduced solids residence time. However, the machine throughput or yield is increased; that is, more sludge can be processed in a given period of time. A reduction in differential speed reduces turbulence inside the pool, yielding a better quality centrate and a drier cake. Differential speed reduction also reduces the rate of wear on the conveyor blades when poorly degritted sludges are handled. The main disadvantage is that machine throughput is reduced.

Operating at too low a differential speed can cause the pile of solids formed in front of the scroll conveyor blade to increase in overall height such that it infringes on the clarified liquid area. This condition may result in the skimming of some fine solids from the top of the cake pile to the centrate, thereby lowering solids capture. At very low differentials, it is even possible to plug a centrifuge with solids.

Process Variables--

Among the process-related variables, the most basic are those associated with the sludge itself. The factors that influence settling and gravity thickening also affect centrifugation. Among these are particle size, shape, and density, viscosity of the liquid, and consistency of the sludge. These variables are generally not under direct control of the operator, but simply result from optimizing upstream treatment processes. In some cases, changes in the operation of an upstream process can affect the thickening and dewatering properties of the sludge generated without reducing performance.

Often, polymers or other chemical conditioners can be used to improve the characteristics of a sludge prior to centrifugation. These polymers generally work by promoting flocculation of the sludge solids, thereby increasing solids capture. Usually flocculating agents are required to achieve an acceptable centrate quality. Although polymers can sometimes improve the compatability of a sludge, their use in centrifuges generally results in a wetter solids cake. The wetter cake results because the additional particles that are captured are very fine and their presence in the solids cake makes it more difficult for the entrapped water to be released. Jar tests are used to select the best polymers and to determine approximate dosage levels, after which operating experience is required to optimize polymer usage. Very small changes in sludge properties sometimes can require that polymer dosages be changed and can occasionally even necessitate the use of different types or combinations of polymers. In addition to wasting money, adding too much polymer (overdosing) can hurt performance.

The solids concentration in the sludge feed can affect both solids capture and cake dryness. A higher feed concentration generally results in lower solids capture and higher concentrations of suspended solids in the centrate. However, depending upon the concentration range, there are some sludges which show better clarification at higher solids concentrations. The concentration of solids in the feed slurry can also affect the optimum coagulant dose, and jar tests should be performed whenever the feed concentration changes significantly. The other effect of higher solids concentrations in the feed is to produce a drier sludge cake. If a drier cake is an objective of centrifuge operation, changes in the operation of upstream treatment steps which affect sludge concentration, such as clarification and thickening, can improve centrifuge performance.

The rate at which sludge is fed to a centrifuge is important. When the volume of sludge centrifuged during a given period of time is increased, the residence time within the centrifuge is decreased and more solids are lost in the centrate. However, a higher feed rate sometimes can result in a drier cake since the additional solids lost in the centrate are fines which tend to entrap water within the cake. When centrifugation is not performed on a continuous basis, taking a longer period of time to centrifuge a batch of sludge can improve performance and possibly can reduce chemical requirements for coagulation. In facilities in which centrifugation is a continuously operated process, the feed rate can only be decreased by increasing the concentration of the sludge feed.

Recycle of concentrated solids usually is performed only in disk-nozzle type centrifuges where several functions are served. First, recycle permits control over the solids residence time in the centrifuge and helps to optimize operation under equilibrium conditions. If the feed rate changes, the recycle rate can be changed accordingly to maintain the required solids residence time to achieve the desired degree of solids concentration. Second, the use of recycle helps keep the velocities high through the concentrating section so that the nozzles do not become plugged. In fact, some centrifuges are designed with larger nozzles (to prevent plugging) which require that recycle be used in order to achieve the necessary solids residence times. The third reason for recycle or for changing the recycle rate is to provide a longer residence time and thereby achieve even greater concentration of the sludge solids.

Another process variable affecting centrifugation is temperature. As is the case in gravity settling and thickening, an increase in sludge temperature reduces the viscosity of the liquid and results in better centrifuge performance since solid particles settle faster. Although temperature is not usually a controlled variable, it is of importance if seasonal changes affect the temperature of the sludge fed to a centrifuge. For example, poorer solids capture and a wetter cake can be expected during winter months when sludge temperatures drop.

Changes in either or machine or process-related variables generally result in changes in centrifuge performance. Some factors which affect performance are not subject to change, such as those related to centrifuge design or sludge thickening and dewatering characteristics. Of the variables which can change, some are used in controlling centrifuge operation while others (such as temperature and feed concentration) may depend upon the operation of upstream treatment processes. The typical effects of these variables on performance are summarized in Table 23. It should be noted that these effects only apply over normal operating ranges when one variable is changed at a time. Generally predictions cannot be made as to the effects of changing several variables at once.

TYPICAL PERFORMANCE VALUES

Two factors must be considered when referring to typical performance values for centrifugation of sludges generated during treatment of metals finishing wastewater. First is the type of sludge. If sodium hydroxide is used for pH adjustment to precipitate metal hydroxides, a light, slimy, and relatively difficult to dewater sludge will result. When lime is used, the amount of excess lime determines the dewatering characteristics of the sludge. When very little or no excess lime is added, most of the sludge formed will be metal hydroxides. If considerable excess lime is used, a large amount of calcium carbonate will be present in the sludge, making it heavier and more easily dewatered.

The second factor to consider is the objective of centrifugation. Most often, centrifuges are used for dewatering and are sized to give a high solids concentration cake. Sometimes, however, centrifuges are intended to function as thickeners prior to final dewatering by another process. This is especially common when disk-nozzle centrifuges are used. The product of centrifugal thickening is still a pumpable liquid, rather than a solids cake.

Table 29 gives some typical applications and performance values for different types of centifuges applied to both metal hydroxide and lime carbonate type sludges.

TROUBLESHOOTING GUIDE

The problems which are commonly associated with centrifuge operations have been summarized in the form of a troubleshooting guide in Table 30. This is a general guide and some specific types or brands of centrifuges may be subject to unique operating problems which usually are covered in the manufacturer's literature.

The most important fact to remember regarding centrifuge operation is that all of the machine and process variables which have been discussed are interrelated in some way. Therefore, when evaluating the effect of any one variable, care must be taken to insure that all others remain unchanged. Otherwise, the cause of a particular problem (or its solution) cannot be determined with certainty.

TABLE 29
TYPICAL PERFORMANCE VALUES FOR CENTRIFUGAL THICKENING AND DEWATERING

Centrifuge Type/Sludge Type	Feed Solids Concentration (%)	Cake Solids Concentration (%)	Solids Recovery (%)	Polymer Dosage (lb.per dry ton)
Solid Bowl (Scroll)				
Metal Hydroxide	0.5-4	15-45	80-95	0-10
High $CaCO_3$		2-8	90-99	20-50
Imperforate Basket				
Metal Hydroxide	0.5-4	10-30	80-95	0-5
High $CaCO_3$		2-8	90-99	15-45
*Disk-Nozzle				
Metal Hydroxide	0.2-1	1-5	85-90	0-10
High $CaCO_3$	0.5-2	2-10	90-95	0-10

*Generally used only for thickening.

TABLE 30
CENTRIFUGATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE (Centrifuge Type)	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 1: Poor centrate quality - low solids recovery.			
1a. Improper chemical dosage. (All types)	- Chemical addition system.	- Setting may be wrong or equipment malfunctioning. If neither, sludge characteristics may have changed.	- Repair or reset equipment or perform jar tests to establish new polymer dosage.
1b. Feed rate too high. (All types)	- Flow data records and performance.	- High flows can reduce detention times. Compare with period of good operation to see if this is the case.	- Reduce flow to centrifuge or reduce sludge recycle.
1c. Feed solids concentration too high. (All types)	- Check feed solids against previous values.	- Determine if good operation has been achieved at the same high feed solids concentration.	- Dilute sludge feed or reduce flow rate.
1d. Pool depth setting wrong. (Solid bowl, basket)	- Check weir or effluent port position and compare with operating records.	- Generally, poor solids capture results from too shallow a pool depth, but not always. Compare with previous performance.	- Adjust weir or port settings.
1e. Improper speed differential between bowl and conveyor. (Solid bowl)	- Differential speed setting and operating records. Excessive build-up of solids in bowl.	- Probably too great a differential causing turbulence in liquid pool. If solids build-up is great, speed differential may be too small.	- Adjust differential speed.
1f. Worn or damaged conveyor flights. (Solid bowl)	- Vibration or unusual noise; excessive build-up of solids in bowl.	- Build-up of solids causes conveyor entrainment into centrate discharge.	- Repair or replace solids conveyor.

TABLE 30
(Continued)
CENTRIFUGATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
1g. Improper bowl speed.(All types)	- Check bowl speed and operating records.	- Insufficient speed results in poor solids capture.	- Increase bowl speed or repair or replace malfunctioning equipment.
1h. Solids discharge line or nozzle plugged.(Disk-nozzle, Solid bowl)	- Check solids discharge line and nozzle for foreign objects and low flow.	- Low sludge discharge results in poor solids capture.	- Unplug solids discharge line or nozzle.
OPERATING PROBLEM 2: Cake or sludge discharge too wet.			
2a. Improper chemical dosage.(All types)	- Chemical addition system and chemical flow rate.	- Setting may be wrong or equipment malfunctioning.	- Repair equipment or adjust dosage. Run jar tests to determine dosage.
2b. Feed rate too high. (All types)	- Flow and performance data.	- High flows reduce retention time. Compare with period of good operation.	- Reduce flow to centrifuge or increase sludge recycle.
2c. Feed solids concentration too low.(All types)	- Solids concentration and operating records.	- Higher feed solids usually give a drier cake.	- Determine if thickened sludge can be obtained from previous treatment steps.
2d. Pool depth too great.(Solid bowl, Basket)	- Weir or effluent put setting.	- Shallower pool exposes more beach or drying deck.	- Adjust weir or put settings.
2e. Improper bowl speed. (All types)	- Check bowl speed and operating records.	- Insufficient speed results in poor sludge compaction.	- Increase speed or repair/replace malfunctioning equipment.
2f. Centrate outlet partially plugged. (Solid bowl, Disk-nozzle)	- Check outlet for foreign objects.	- Low centrate flow results in thinner sludge discharge.	- Clean outlet port.

TABLE 30
(Continued)
CENTRIFUGATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
OPERATING PROBLEM 3: High torqe alarm.			
3a. Feed rate too high. (All types)	- Flow records.		- Reduce flows.
3b. Feed solids too high.(All types)	- Solids data records.		- Dilute sludge or reduce flow rate.
3c. Foreign material in machine.(All types)	- Inspect interior.		- Remove foreign material.
3d. Gear unit mis-aligned.(All types)	- Vibration.		- Correct alignment.
3e. Faulty bearing, gear.(All types)	- Inspect gear unit.		- Replace faulty parts.
OPERATING PROBLEM 4: Excessive vibration.			
4a. Improper lubrication. (All types)	- Check lubrication system.		- Correct lubrication.
4b. Improper adjustment of vibration isolators.(All types)	- Vibration isolators.		- Adjust isolators.
4c. Discharge funnels may be contacting centrifuge.(All types)	- Position of funnels.		- Reposition slip joints at funnels.
4d. Portion of conveyor flights may be plugged with solids causing imbalance. (Solid bowl)	- Interior of machine.		- Flush out centrifuge.
4e. Gear box improperly aligned.(All types)	- Gear box alignment.		- Align gear box.
4f. Pillow block bearings damage. (All types)	- Inspect bearings.		- Replace bearings.

TABLE 30
(Continued)
CENTRIFUGATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
4g. Bowl out of balance. (All types)			- Return rotating parts to manufacturer for rebalance.
4h. Parts not tightly assembled. (All types)			- Tighten parts.
4i. Uneven wear of conveyor. (Solid bowl)	- Inspect conveyor.		- Resurface, rebalance.
OPERATING PROBLEM 5: Sudden increase in power consumption.			
5a. Contact between bowl and accumulated solids in centrifuge case.(All types)	- Solids plows; look for polished area on outer bowl.		- Apply hard surfacing to to areas with wear.
5b. Effluent pipe plugged.(All types)	- Check for free discharge of solids.		- Clear effluent pipe.
OPERATING PROBLEM 6: Gradual increase in power consumption.			
6a. Conveyor blade wear. (Solid bowl)	- Conveyor condition.		- Resurface blades.
OPERATING PROBLEM 7: Spasmodic, surging solids discharge.			
7a. Pool depth too low. (Solid bowl)	- Plate dam position.		- Increase pool depth.
7b. Conveyor helix rough. (Solid bowl)	- Improper hard surfacing or corrosion.		- Refinish conveyor blade areas.
7c. Feed pipe (if adjustable) too near drainage deck.(Solid bowl)			- Move feed pipe to effluent end.

TABLE 30
(Continued)
CENTRIFUGATION TROUBLESHOOTING GUIDE

PROBABLE CAUSE	CHECK OR MONITOR	REASON	CORRECTIVE ACTION
7d. Machine vibration excessive (Solid bowl, Disk-nozzle)	- See Item 4.		- See Item 4.
OPERATING PROBLEM 8: Centrifuge shuts down (or will not operate).			
8a. Blown fuses. (All types)	- Fuses.	- Overload or weak fuse. May be wrong size fuse.	- Replace fuses, flush machine. If fuse blows on start-up, mechanical inspection is required.
8b. Overload relay tripped. (All types)	- Overload relay.		- Flush machine, reset relay. If relay trips on restart, mechanical inspection is required.
8c. Motor overheated, thermal protectors tripped.(All types)	- Thermal protectors.	- Insufficient ventilation. High air temperature.	- Flush machine, reset thermal protectors. Check fan on motor.
8d. Torque control tripped.(All types)	- See Item 3. Check torque indicator.	- Torque indicator may be stuck or defective.	- Replace or repair.
8e. Vibration switch tripped.(All types)	- See Item 4.	- Switch may be defective.	- Replace.

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